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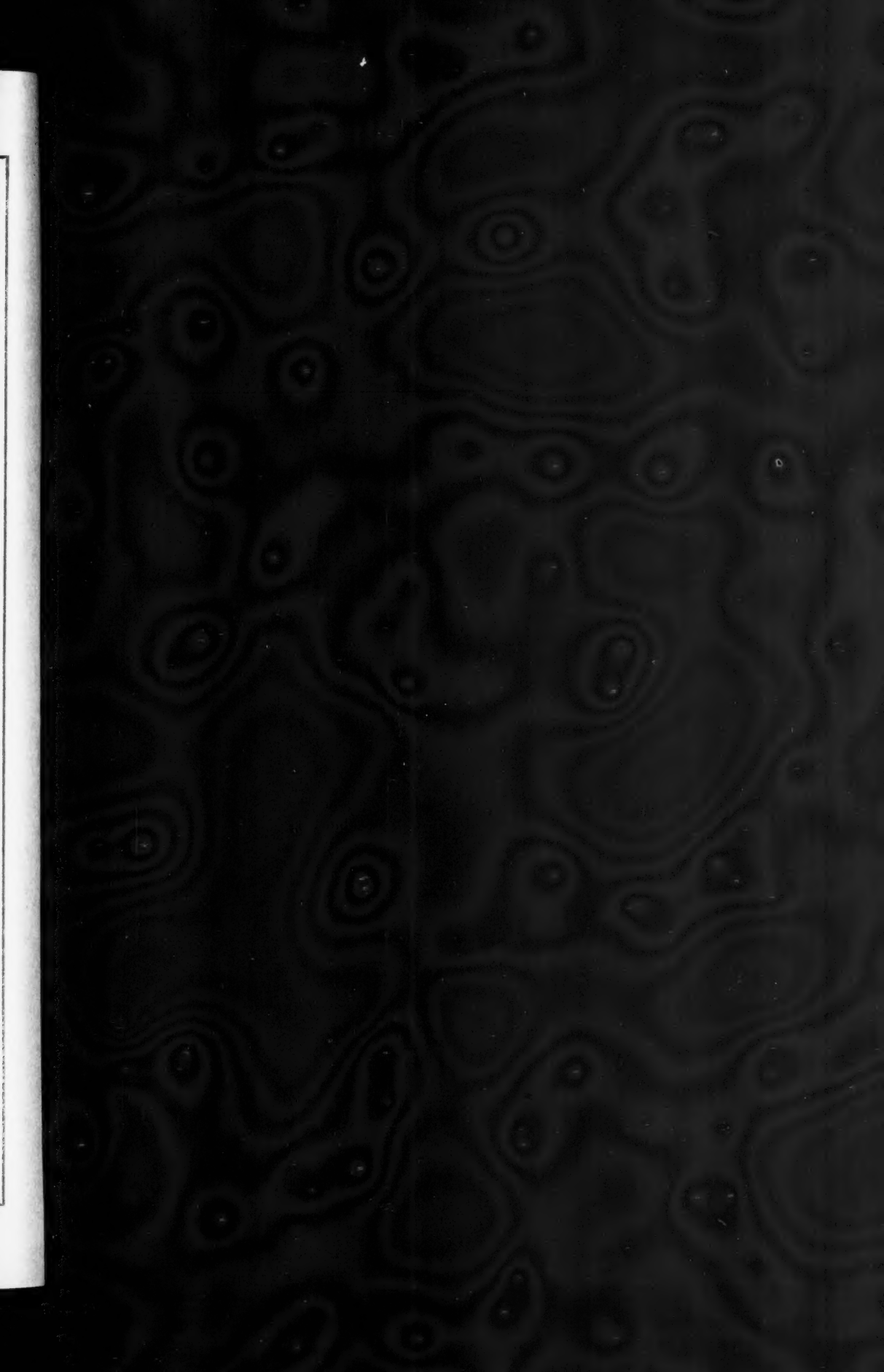

ON THE EXISTENCE OF DAILY CHANGES IN THE BACTERIAL NUMBERS IN AMERICAN SOIL

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Rothamsted Experimental Station

Received for publication May 6, 1926

The changing numbers of the various groups of microörganisms in a field soil must be a factor of vital importance to a proper understanding of the relationship of these organisms to their environment. It has long been known that the bacterial numbers are subject to seasonal changes. The numbers found at daily intervals has been studied recently by Cutler, Crump, and Sandon (2) at Rothamsted. These investigators found that in samples of soil taken at daily intervals from a plot on Barnfield, the bacterial counts obtained by the plate method showed striking variations from day to day. Before attributing these variations to true increases or decreases in the bacterial population counted, two possible sources of error must be considered.

In the first place there is a necessary experimental error in making the counts. In the work referred to, the platings were made by different workers, but in tests that were conducted, no variation in the technique could be detected, the factor limiting the accuracy of the counts being in nearly all cases the random distribution of the bacteria in the diluted suspension (4). This factor, which is calculable, was wholly insufficient to account for the fluctuations. The second source of error arises from the fact that samples taken at daily intervals are also taken at intervals in space, so that before the results are attributed to changes in bacterial numbers over a period of time, the possibility that they represent uneven distribution of the bacterial population in space must be excluded. This was done (2) by taking, on three occasions, 4 simultaneous samples from different parts of the plot. The counts obtained were in no case significantly different among the 4 samples. Furthermore, for 15 consecutive days, duplicate samples were taken 6 yards apart and the similar fluctuations in bacterial numbers were found in the duplicate series (2, p. 338). This rules out the possibility of accounting for the fluctuations found in Barnfield as being due to uneven distribution of the bacteria over the plot. Similar daily fluctuations in bacterial counts were found on Broadbalk (1) but there was no evidence as to whether the phenomenon was a general one occurring in other districts and under different soil conditions.

Recently, however, an important series of daily bacterial counts has been made at Washington, D.C., by Smith and Worden (6), who found fluctuations in the count from day to day. In this experiment, the plot selected was on a lawn, the sod of which was removed and the soil dug over.

The conditions were thus very different from those in the Rothamsted experiments. The method of sampling was also different, each count being made from a single core, instead of from a composite sample of 6 cores mixed together. Each day, however, the authors took 2 samples some distance apart and made separate counts from each, so that the influence on the results of the uneven distribution of the bacteria can be checked to some extent by comparing the variation in bacterial numbers between the 2 simultaneous samples with the difference found on consecutive days. The authors, on making such a comparison, concluded that the variation between simultaneous samples was greater than the fluctuations in the count from one day to the next. Their method of making this comparison is not valid, however, since they have compared the differences between individual simultaneous samples with day to day changes in the mean of 2 samples. Moreover, in sampling the plot, consecutive daily samples were taken from cores only 1 foot apart, whereas the 2 samples taken the same day were from spots several feet distant.

From the authors' data it is possible to make a decisive test of the reality of day to day changes in this particular set of counts, for if the whole of the variation observed in successive counts were due either to local differences or to the errors of random sampling, the two samples taken on the same day should show no positive correlation; indeed, since the simultaneous samples were taken from spots further apart than would be pairs chosen at random, a slight negative correlation should be anticipated. On the other hand, general changes in the bacterial numbers, affecting the whole plot, will tend to produce a positive correlation between simultaneous samples. If such a significant positive correlation between simultaneous samples exists, it excludes the possibility of the fluctuating bacterial counts being entirely due to uneven distribution of the bacteria. The authors' data are the more valuable because counts were made on 3 different media, namely, Löhnis' soil extract agar (5), Waksman's egg albumen agar (8), and Thornton's mineral salts agar (7). The counts on the first of these media from 32 pairs of samples taken between August 13 and September 19, show a positive correlation between simultaneous samples of $+0.4955$. The egg albumen agar was used for only 19 pairs of simultaneous samples taken between August 28 and September 19, which show a positive correlation of $+0.5673$. These two correlations must each be judged undoubtedly significant (3, p. 174). The mineral salts media was similar to that employed by Cutler, Crump, and Sandon for the Barnfield counts, though the temperature and period of incubation were different from those used at Rothamsted. The results obtained on this medium are thus more nearly comparable with the Barnfield counts. On it the 32 pairs of simultaneous counts obtained show a positive correlation of $+0.7744$. The probability against this occurring if the count differences were due to soil sample variation is about a million to one. Figures 1, 2, and 3 show the correlation between simultaneous samples on the three media. The existence of this correlation proves that the daily changes in the counts cannot be ascribed merely to uneven distribution of the bacteria within the area sampled.

The correlations stated above do not exclude the effect of slow changes in the bacterial numbers from the beginning to the end of the observations, changes to which Smith and Worden call attention, and which might perhaps properly be called seasonal. The authors have, therefore, recalculated the three values, eliminating a linear term representing the steady increase (or decrease) in the numbers (3, p. 171). The results show that the association between counts made on the same day is not to any large extent attributable to seasonal changes, but that there remain substantial and significant correlations when

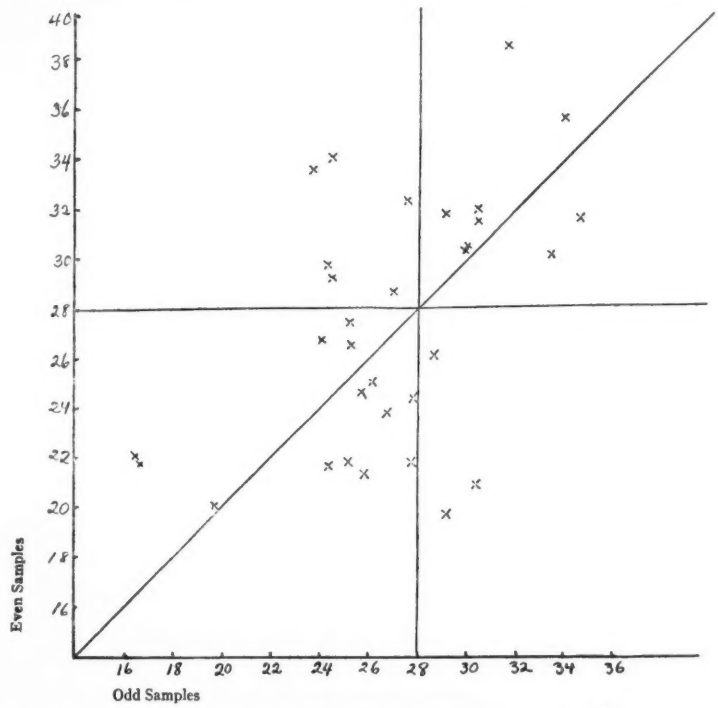

FIG. 1. CORRELATION BETWEEN SIMULTANEOUS SAMPLES PLATED ON $\frac{1}{2}$ SOIL $\frac{1}{2}$ EXTRACT AGAR
(Smith and Worden's data)

the seasonal effect is eliminated. For the soil extract medium the correlation is reduced to +0.3808, a value which would occur by chance not more than once in 20 trials. For the egg albumen medium the correlation has risen to +0.6615 and for the mineral salts agar it has fallen to +0.7060, both these values being of quite unquestionable significance.

In speaking of the counts published by Smith and Worden as affording confirmation in American soil of continual changes similar to those observed at Rothamsted, it should be stated that we have never lost sight of the fact that systematic variations from day to day in the manipulative technique might

in many ways simulate actual variations in the bacterial population. In the case of the work at Rothamsted, the particular observations upon which our conclusions are based, as well as the whole body of comparable routine observations, have been so thoroughly tested and confirmed as to leave no residuum of doubt as to the objective reality of the phenomenon. Obviously, in the case of work done elsewhere, we have no such direct evidence of uniform technique and we can only demonstrate the *existence* of day to day variations of the same *type* as those observed at Rothamsted, without excluding the

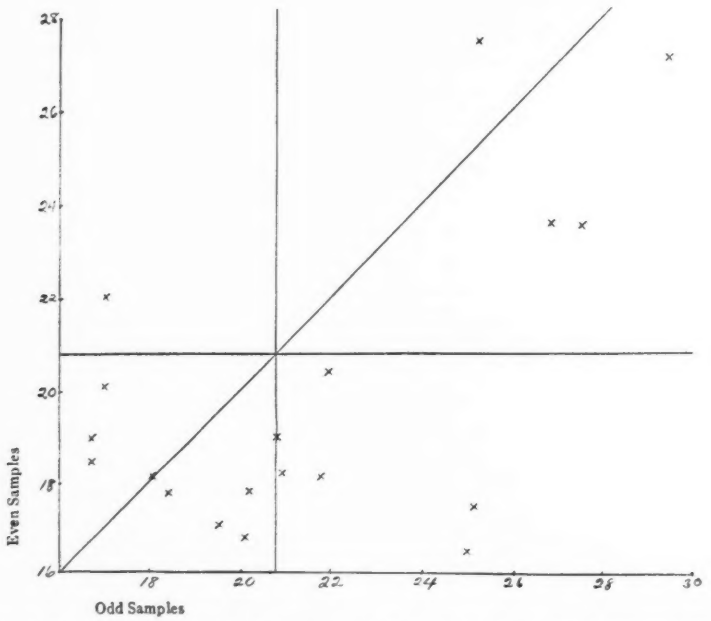

FIG. 2. CORRELATION BETWEEN SIMULTANEOUS SAMPLES PLATED ON EGG ALBUMEN AGAR
(Smith and Worden's data)

possibility that variations in technique may have contributed to, or may be responsible for, the variations observed.

It is interesting that the closest correlation between counts from simultaneous samples was found when the mineral salts medium was used. If the counts obtained on this medium from individual cores be plotted separately (fig. 4) it is seen how similar are the changes in numbers in different regions of the plot. The fluctuations are more apparent on this medium than on either of the other media. The authors are probably right in attributing this to the selective action of the mineral salts medium. When using the plate method there is never any question of obtaining total bacterial counts, because no single

medium can possibly allow all physiological groups of the bacteria to develop. Consequently the comparative number of colonies that develop from a soil plating on a given medium is no criterion of the value of that medium for investigation. On the other hand it is essential to a satisfactory technique that

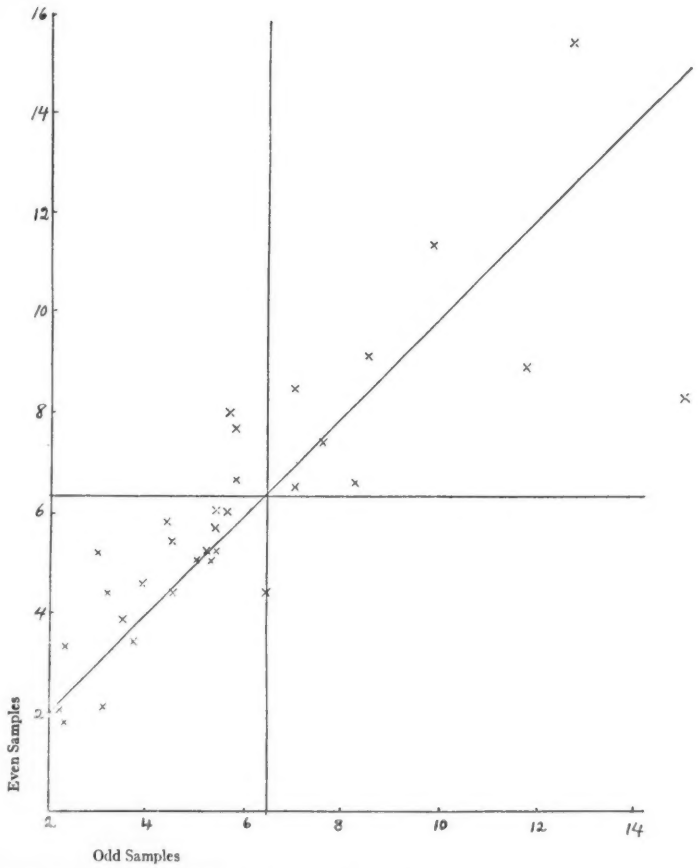

FIG. 3. CORRELATION BETWEEN SIMULTANEOUS SAMPLES PLATED ON MINERAL SALTS AGAR

(Smith and Worden's data)

the agreement between parallel plates should justify the assumptions upon which the dilution method is based, as can be tested by calculating χ^2 (4), and this agreement has so far been demonstrated only with the mineral salts agar. The greater number of colonies that appeared on the soil extract-medium probably indicates, as is suggested by Smith and Worden, that it is a

less selective medium than the mineral salts agar. For this reason it is less appropriate to the present type of investigation. It is unlikely that the numbers of all groups of bacteria fluctuate simultaneously. Some groups will increase while others will diminish in numbers. Consequently a selective medium is best suited to the study of these fluctuations because it diminishes the chance that a fall in the numbers of one group will be obscured on the plate counts by the increase of another group.

The work of Smith and Worden thus indicates that daily fluctuations in the state of the bacterial population which are similar in type to those already found at Rothamsted, exist in American soil, and also that the fluctuations occur under widely different soil conditions. There can be little doubt that the phenomenon is of general occurrence. It is possible, however, that only under exceptional conditions will the soil be sufficiently uniform to permit of its easy detection.

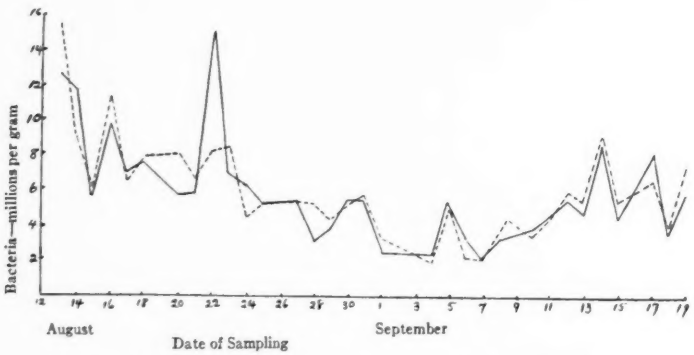

FIG. 4. DAILY COUNTS ON MINERAL SALTS MEDIUM

Bacterial numbers from the duplicate samples separately plotted. (Smith and Worden's data.)

SUMMARY AND ABSTRACT

The daily bacterial counts published by Smith and Worden show variations which cannot be explained by unequal distribution of bacteria in the soil, or by seasonal changes in bacterial numbers.

On all three media employed by them, significant positive correlations in bacterial numbers between simultaneous samples were obtained.

The similar daily fluctuations occurring in different parts of the plot show most clearly on Thornton's mineral salts medium.

Provided the manipulative technique of Smith and Worden was sufficiently uniform, the results afford evidence of the existence, in very different conditions, of fluctuations in bacterial numbers similar to those observed at Rothamsted.

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STUDIES OF THE REMOVAL OF NUTRIENTS FROM SUBSOIL BY ALFALFA

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Because of the deep rooting habit of alfalfa, frequent references have been made to the withdrawal of nutrients from the lower horizons of the soil profile by this crop. Insofar as the writer is aware, however, no data have been presented which prove that alfalfa actually does remove nutrients from this portion of the soil profile.

Alway, McDole, and Rost (1) found that inoculated alfalfa grew on certain subsoils of eastern Nebraska almost as luxuriantly as on the surface soils. On the other hand Harmer (2) found only two out of seven subsoils from Minnesota capable of producing as good a growth of inoculated alfalfa as the corresponding surface soils. It should be noted that the conditions of both these experiments were such as to allow the surface roots to absorb the nutrients.

In his excellent review of studies of the root habits of alfalfa, Weaver (6) points out that the nature of the root system is greatly modified by soil, climatic conditions, and height of water table. Garver (3) found that variety, frequency of cutting, and thickness of stand were potent factors in determining the nature of the root system. Weaver's own observations show that on fairly porous upland soils of not too restricted rainfall, the tap root is the main feature and that laterals below the first foot or eighteen inches are comparatively few and very short. Ten Eyck (5) on the other hand reports the major portion of the fibrous roots below the four-foot level.

The studies here reported were undertaken with the purpose of obtaining some definite information as to whether alfalfa, under the conditions of the experiment, actually does remove nutrients from the subsoil and further, whether it is capable of doing so when nutrients are added to the lower soil horizon.

METHOD OF PROCEDURE

The best method of procedure was considered to be one by which the roots could be restricted from ramifying in the surface soil without otherwise disturbing the plant. Glass cylinders about two inches in diameter and eight

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inches long, which could be slipped over the crowns of the smaller plants, seemed to offer the greatest possibility, for the following reasons:

The amount of soil contained in the cylinder should offer minimum opportunity for nutrient absorption by the surface roots, especially since the water-retaining power of this small amount of soil would be so slight that it should be dried out very quickly after a rain. The glass walls of the cylinder would render impossible even the slightest trace of horizontal salt movement. The plants would thus be forced to rely on the nutrients which might be obtained through the lower portion of the root system, and the very small amount from the soil in the cylinders, or else draw on stored foods. The cylinder could be placed without any disturbance of the lower root systems.

In the spring of 1923 when growth was starting, the soil to a depth of about nine inches was carefully removed from around a number of two-year-old alfalfa plants growing in Coloma loamy sand. Cylinders were carefully slipped over these plants, so as not to damage the shoots, and placed with their tops just below the bottom of the crowns of the plants. The soil was replaced around the cylinders and the cylinders themselves were filled with soil from a depth of about three feet in some cases and in others with surface soil.

To determine whether nutrients added to the lower soil horizons would be absorbed and enhance plant growth, 500 cc. of Shive's three-salt solution of double strength was added at depths of 18 inches and 36 inches respectively. The solution was delivered very close to the tap root through an iron pipe inserted to the proper depth in an auger hole. The nutrient solution was first applied early in the spring about the time growth started and the application was repeated after the first and second cuttings. For comparison other groups of plants, not fitted with glass cylinders, were treated with the solution at the same depths. Starting with the application after the second cutting in 1924 the nutrient solution was made four times its usual strength, with the thought that possibly the quantities of salts in the double strength solution were not sufficient to induce a maximum response in the plants.

The growth from each plant was cut with shears, air-dried, and weighed individually, so that a complete record of the performance of each plant, cutting by cutting for a period of three years is available, with the exception of the second cutting in 1923, which was accidentally destroyed by a farm hand.

In 1924 examination showed that in some cases the roots had grown out around the bottom of the cylinders and had then turned upward and ramified in the surface soil (plate 1, fig. 1). This upward growth might be interpreted as indicating either a more plentiful supply of nutrients or water or possibly both in the surface soil than in the lower soil horizons. Roots which had so developed in the surface horizon were cut off.

DISCUSSION OF RESULTS OF PRELIMINARY EXPERIMENTS

Since these experiments were preliminary and included only a small number of plants under each treatment, it seems advisable to give only the general indications suggested by the results.

When the plants surrounded with cylinders containing surface soil are used as a basis of comparison and when each cutting is considered separately, the data indicate that during 1923 and 1924 nutrient solution applied at a depth of 18 inches stimulated quite markedly the growth of plants in cylinders filled with subsoil. By 1925, however, 50 per cent of the plants so treated had died and the growth of the others was inferior to that of plants in cylinders filled with subsoil but receiving no solution.

Strangely, plants not surrounded by cylinders but receiving solution at a depth of 18 inches did not show as much effect from the application, during the later cuttings in 1923 and 1924, as those surrounded by cylinders and receiving solution at the same depth. More of these plants lived through the season of 1925 but their growth was no more satisfactory than that of the plants in cylinders.

Addition of nutrient solution at a depth of 36 inches to plants in cylinders filled with subsoil resulted in an increased growth in 1923, but seemed to be of no special value to the crop in 1924. Because of the very poor condition of these plants no yields were taken in 1925.

Plants not in cylinders but receiving nutrient at a depth of 36 inches showed less influence from the treatment during 1923 than those in cylinders and receiving solution at the same depth. The second cutting of 1924 showed a gain, but for the other cuttings there was no advantage.

In general it may be said that inclosure in cylinders and the consequent exclusion of roots from the surface soil did not appear to be detrimental to alfalfa plants. On the other hand there was more tendency for plants so inclosed to respond to applications of nutrient salts in the lower soil horizons.

DISCUSSION OF RESULTS OF LATER EXPERIMENTS

In 1924 several treatments were selected as being best suited to answer the questions in mind, and groups of plants receiving these treatments were brought into the experiment. In addition a group of plants receiving nutrient solution in a trench about 3 or 4 inches deep around each plant was added to the series.

In compiling the data for the plants brought under treatment at this time, the yields from those plants not placed in cylinders and receiving no nutrient solution were taken as a basis for comparison. The data in table 1 give the percentage of each cutting as related to the corresponding cutting of the control plants. Since it was impossible to select plants of equal size for the various groups and since some plants winter killed, the first cutting each year is taken as a starting point or basis of comparison for the other cuttings.

The second cutting of the plants receiving solution at a depth of about 3 inches bore a lower relation to its check than the first cutting to its check. The third cutting shows a negligible increase over the percentage for the first cutting. It is evident, therefore, that the addition of the solution has not increased the yield for 1924. In 1925 the second and third cuttings show a

marked increase over the corresponding cuttings of the untreated plants, which indicates a distinct benefit from the added nutrient.

The plants not in cylinders but receiving solution at a depth of 36 inches show no influence of the treatment the first year. The second year, however, a distinct increase for the second and third cuttings is noted.

Plants not surrounded by cylinders showed no influence of nutrient solution applied at a depth of 60 inches, until the third cutting of 1925 when a distinct increase in growth was noted.

The first cutting of the plants in cylinders but receiving no solution was 36.3 per cent of the first cutting of the untreated plants, indicating that the plants in cylinders were much the smaller. The second cutting was virtually the same percentage but the third cutting showed a considerable increase. In 1925 the second and third cuttings showed an appreciable gain in percentage growth over the corresponding cuttings of the untreated plants. These data

TABLE 1

Yield of air-dry tops from alfalfa plants

The relation of each cutting to the corresponding cutting from the control plants

TREATMENT	1924			1925		
	First cutting	Second cutting	Third cutting	First cutting	Second cutting	Third cutting
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Solution at 3 inches	111.7	96.5	113.9	75.9	101.2	117.2
Solution at 36 inches	89.1	81.3	86.7	50.9	66.7	77.0
Solution at 60 inches	51.2	47.8	49.2	31.1	30.1	57.2
Plants in cylinders; no solution	36.3	33.6	49.9	23.8	36.9	44.8
Plants in cylinders; solution at 36 inches	21.9	43.9	40.0	7.8	15.4	13.6
Plants in cylinders; solution at 60 inches	43.4	53.1	51.3	27.4	35.2	48.2

indicate that the cylinders were not limiting the growth of the plants and that an adequate supply of nutrients was being obtained. Whether the source of supply was the subsoil is an open question, since no withdrawal of stored material could be measured.

Plants in cylinders and receiving nutrient solution at a depth of 36 inches show a decided increase in percentage yield over the corresponding cuttings of the untreated plants, beginning with the first cutting each year. This indicates a decidedly beneficial effect of the solution, which agrees with the 1925 results from the plants receiving solution at the same depth but not inclosed in cylinders, but disagrees with the results for 1924.

Solution applied at a depth of 60 inches to plants in cylinders produced an appreciable increase in growth for the second and third cuttings for both years. This again does not agree with the results obtained when solution was applied at a similar depth to plants not in cylinders.

It is interesting to note that although the above data indicate no restriction of growth as a result of preventing root development in the surface soil by

means of glass cylinders, the plants so treated showed a decided increase in growth as a result of applications of nutrient solution at depths of 36 inches and 60 inches. Plants not inclosed in cylinders did not show such a definite response to additions of nutrients.

The data from both sets of experiments seem to justify the conclusion that nutrient solution applied at depths of 18 inches, 36 inches, and 60 inches increased the growth of alfalfa, especially when the roots were excluded from the surface soil. These results indicate that the lower portion of the root systems are capable of absorbing nutrients in appreciable quantities. Excavation of several specimens showed that a large development of fibrous roots had occurred at the depth of application of the nutrient solution. Plate 1, figure 2 shows this development in plants receiving nutrient at the 36-inch depth.

Nutrient solution applied around the surface roots of the plants did not stimulate growth the first year, and during the second year the increase was not so great as one might expect.

TABLE 2

Growth records of alfalfa plants

Weight of air-dry tops per cutting

PLANT NUMBER	1923		1924			1925		
	First cutting	Third cutting	First cutting	Second cutting	Third cutting	First cutting	Second cutting	Third cutting
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	26.9	13.0	121.2	36.4	21.3	10.4	11.2	3.0
2	18.7	10.5	100.8	37.6	25.2	31.0	20.6	13.2
3	3.1	0.6	31.0	13.3	11.6	15.7	11.6	4.0
4	....	....	32.7	28.9	14.9	19.0	8.1	3.4
5	....	....	6.4	6.3	4.1	7.9	5.4	2.35
6	....	....	178.1	73.0	44.6	161.8	53.0	22 0

VARIATION IN GROWTH OF ALFALFA PLANTS

The erratic behavior of individual plants is one point emphasized by these studies. As an illustration, the performance of several plants by cuttings is given in table 2. It is evident that if definite conclusions are to be drawn, studies of alfalfa (and probably the same is true of other plants, having large facilities for food storage) should include large numbers of plants.

GROWTH OF ALFALFA PLANTS WITH ROOTS EXCLUDED FROM SURFACE 15 INCHES OF SOIL

In order to note the effect of yet more drastic treatment on the behavior of alfalfa, 2-inch glass cylinders 15 inches long were placed around seven plants. The cylinders were filled with quartz sand. The behavior of the plants under this extremely abnormal condition is shown in table 3.

It is interesting to note that notwithstanding the extremely adverse conditions under which these plants were placed, they all lived through the first year and until after the first cutting of the second year, when only one died. After the second cutting of 1924, another plant succumbed, all of the others living through the year. In the spring of 1925 only two plants were alive and these grew thriftily throughout the season. Whether the heavy mortality in the second year was due to a depletion of food reserves in the roots with a resulting decrease in size of root, increase in water content, and consequent susceptibility to winter injury as reported by Nelson (4) was not determined, but seems probable.

It is a remarkable fact that two plants should live and produce three cuttings annually for three years under the conditions of the experiment. It is evident

TABLE 3

Growth of alfalfa plants surrounded by glass cylinders 2 inches in diameter and 15 inches long

Weight of air-dry tops for each cutting

PLANT NUMBER	1923		1924			1925		
	First cutting	Third cutting	First cutting	Second cutting	Third cutting	First cutting	Second cutting	Third cutting
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	7.4	3.6	32.2	20.5	18.3	....	....	....
2	1.5	0.6	41.0	....	....	....	....	....
3	18.4	2.5	4.4	2.8	....	....	....	....
4	9.5	5.1	51.9	35.7	32.1	33.1	14.1	13.5
5	7.6	3.8	11.8	7.7	6.9	....	....	....
6	18.2	6.8	61.8	29.2	28.9	....	....	....
7	6.2	2.1	47.9	29.9	19.7	58.8	14.6	12.5

that nutrients must either have been absorbed from the lower soil horizons or else the plants were making use of stored reserves. From data which will appear in another paper, this latter suggestion seems very plausible.

ABSORPTION OF WATER BY THE LOWER ROOT SYSTEM

In working among the plants, the author noted that those which had been enclosed in cylinders the previous day showed no signs of wilting even during the hotter portions of the day. This seemed remarkable since the sand used for filling the cylinders contained only a small amount of moisture. To test still further their resistance to wilting, three plants were fitted with 8-inch cylinders and three with 15-inch cylinders filled with quartz sand. These operations were performed at 10:00 a.m. on May 4, which was a bright warm day. At 4:00 p.m. on the following day, which was also bright and warm, there were no signs of wilting. The conclusion is unavoidable that the lower roots were absorbing water at a sufficient rate to meet the transpiration requirement of the plants.

SUMMARY

The placing of glass cylinders 2 inches in diameter and 8 inches long around alfalfa plants, thus excluding the roots from the surface soil, did not appear to decrease the growth of the plants as measured by the weight of air-dry tops. Three cuttings were taken for two successive years.

Nutrient solution applied near the tap roots at various depths increased the growth of tops of plants inclosed in cylinders. Plants not having their root system restricted by cylinders showed little response to applications of nutrient solution.

When nutrient solution was applied to the lower soil horizons a considerable development of fibrous roots occurred in the region of application.

The plants under observation showed a great variation in behavior as measured by individual cuttings.

Five out of seven plants enclosed in glass cylinders 2 inches in diameter and 15 inches long filled with quartz sand, lived for two years, three cuttings being taken each year. Two of the plants lived for three years.

When plants with several inches of top growth were inclosed in 15-inch cylinders filled with dry quartz at 10:00 a.m. on a warm bright day, no evidence of wilting was apparent at 4:00 p.m. on the following day, which was also bright and warm.

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PLATE 1

FIG. 1. These roots grew out around the bottom of the 8-inch cylinders and then turned upward and ramified in the surface soil.

FIG. 2. A large number of fibrous roots developed near the point of application of nutrient solution, at the 36-inch depth.

FIG. 1

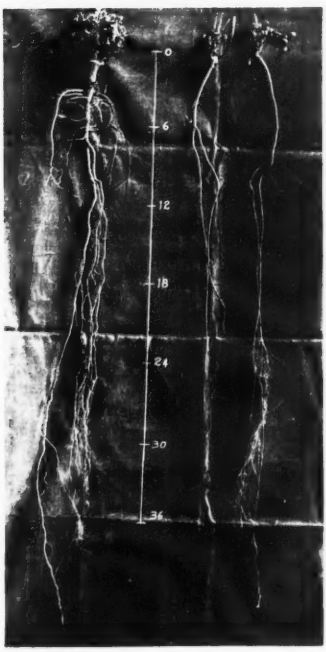

Fig. 2

THE MICROFLORA AND THE PRODUCTIVITY OF LEACHED AND NON-LEACHED ALKALI SOIL

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The permanent reclamation of alkali soil rests upon the installation of underground drains and the leaching from the soil of the injurious constituents. The success of this method varies with the physical and chemical nature of the soil. With some soils it is a success whereas with others it is only a partial success or a total failure. Recent experiments show that these failures are due to the profound changes which the soluble salts have exerted on the composition of the soil; which in turn has changed so profoundly the structure of the soil that leaching becomes impossible. Such a condition can be overcome only by a preliminary treatment. Some soils, even after leaching, remain barren or produce only meagre crops for a number of years.

The non-productive period may be due to physical, chemical, or biological changes which have occurred within the soil because of its alkali content or the changes incidental to the leaching process. It is quite certain that the microflora would be profoundly influenced by the salt content of the soil. It is also reasonable to believe that considerable time would have to elapse after the leaching of such a soil before a normal active microflora would become established within it. The leaching of the soil would remove not only the injurious salts but considerable of the available plant-food. More plant-food would be rendered available only after the physical and chemical properties of the soil become suitable for bacterial growth and the soil became properly inoculated. Hence, this work was undertaken to determine the number of microorganisms, the biological changes occurring, and the productivity of natural and artificially leached and non-leached alkali soil which had been treated in various ways to re-establish its microflora.

PLAN OF EXPERIMENT

Two-gallon jars, provided with a half-inch hole near the lower edge were used. Into the holes were fitted rubber stoppers with glass tubes so that all drainage water could be collected, measured, and analyzed. A small quantity of glass wool was placed over the opening and the bottom of the jar was covered

[1] Valuable assistance in the analytical work was given by Professor Carter, Mr. Lund, Mr. Nelson, and Mr. Pulley.

to a depth of 2 inches with fine gravel. This was covered with a layer of glass wool. Sufficient soil to fill the pots was mixed with the requisite salts, packed into the pots, and the moisture content made to 20 per cent. Some pots contained untreated soil, others natural alkali soils, whereas still others contained synthetic alkali soil. The salt treatments were as follows:

12 pots were filled with the college farm soil untreated.
12 pots were filled with the college farm soil plus 2 per cent sodium chloride.
12 pots were filled with the college farm soil plus 2 per cent sodium sulfate.
12 pots were filled with the college farm soil plus 2 per cent sodium carbonate.
12 pots were filled with the college farm soil plus 1 per cent sodium chloride plus 1 per cent sodium sulfate.
12 pots were filled with the college farm soil plus 1 per cent sodium chloride plus 1 per cent sodium carbonate.
12 pots were filled with the college farm soil plus 1 per cent sodium sulfate plus 1 per cent sodium carbonate.
12 pots were filled with the college farm soil plus 2/3 per cent each of sodium chloride, sodium sulfate, and sodium carbonate.
12 pots were filled with Corinne soil in which sodium chloride was the predominating salt.
12 pots were filled with Richland Acre soil in which sodium sulfate was the predominating salt.
12 pots were filled with Benson soil in which sodium carbonate was the predominating salt.

All of the soils stood for two months with a moisture content of 20 per cent before leaching so that the various reactions occurring because of the treatment would tend toward equilibrium. After this, six pots in each series were leached by keeping on them a "water head" as nearly constant as possible. All drain water was collected and analyzed. The results have been previously reported (6).

At the end of the leaching period (640 days) the soils were sampled and analyzed as to numbers, ammonifying, nitrifying, and nitrogen-fixing powers. After sampling, the pots were treated as follows:

Without further treatment two of the leached and two of the unleached pots from each series were seeded to crimson clover. Two of the leached and two of the unleached pots from each series received barnyard manure at the rate of fifteen tons per acre and were then seeded to crimson clover. Two of the leached and two of the unleached pots from each series received 50 cc. soil extract, which was made by shaking 100 gm. of a fertile soil in 1000 cc. of water, allowing it to settle, and then pippetting off 50 cc. The pots were then seeded to crimson clover.

The plants including roots were harvested at the time of full bloom and total dry matter and percentage of nitrogen determined. The soil from each pot was then sampled and analyzed after which it was manured or inoculated with a water extract, as outlined above, and then seeded to barley. When ripe, the barley was harvested; the pots were resampled, retreated, and again seeded to barley. Hence, we have data on three samplings of the soil made at different times, and data on three crops—one of clover and two of barley. Four analyses were made on each sample of soil, hence, each result for numbers, ammonifying, nitrifying, and nitrogen-fixing powers represents the average of eight analyses made on two pots of soil receiving the same treatment.

COMPOSITION OF SOIL USED

The work was conducted on four different soils:

1. From the College Farm east of the Plant Industry Building.
2. From Corinne.
3. From Benson Ward.
4. From Richland Acres.

TABLE 1

Physical composition of soils

CONSTITUENTS	COLLEGE FARM SOIL	CORINNE SOIL	BENSON WARD SOIL	RICHLAND ACRES SOIL
	per cent	*per cent*	*per cent*	*per cent*
Sand	36.6	17.5	42.5	4.8
Fine sand	30.6	17.3	20.9	29.6
Coarse silt	18.8	28.5	19.0	27.0
Medium silt	6.0	15.9	3.8	13.1
Fine silt	2.3	5.3	2.3	10.2
Clay	3,5	7.4	6.1	9.4
Moisture, soluble salts, and loss	2.2	8.1	5.4	5.9

TABLE 2

Leaching necessary to remove the greater portion of the soluble salt from the soil

SOIL	TREATMENT	DURATION OF LEACHING PERIOD	WATER LEACHED
		days	*liters*
College	None	18	121
College	2 per cent NaCl	49	84
College	2 per cent Na_2CO_3	274	140
College	2 per cent Na_2SO_4	29	175
College	1 per cent NaCl plus 1 per cent Na_2SO_4	25	153
College	1 per cent NaCl plus 1 per cent Na_2CO_3	640	
College	1 per cent Na_2SO_4 plus 1 per cent Na_2CO_3	203	85
College	0.66 per cent each NaCl plus Na_2SO_4 plus Na_2CO_3	199	240
Corinne		211	79
Richland Acres		38	94
Benson Ward		139	247

Soil 1 was a good productive soil and was made unproductive by the addition of the salts listed above. Soils 2, 3, and 4 were natural alkali soils containing sufficient alkali to prevent the growth of all vegetation except a few salt-tolerant plants. The physical analyses of the four soils as determined by the Yoder (8) elutriator are given in table 1.

Soils 1 and 3 are sandy loams, whereas soils 2 and 4 are fine sandy loams. These soils should be more difficult to leach than a sand and much less difficult than a tight or heavy clay. However, they approximate the composition of

many of our alkali soils. Hence the results obtained in this work should give a lead to what may be expected in the field with the various alkali soils.

The soils were all leached until an analysis of the drain water indicated that the greater quantity of the soluble salts which could be removed by water had been washed from the soil. The time required and the quantity of water necessary to accomplish this, varied greatly with the different soils, as may be seen from the summarized results given in table 2.

The water passed rapidly through the normal soil during the first 48 hours yielding an average hourly leaching of 24.4 cc. After this there was a slight decrease, but this soil readily leached throughout the duration of the experiment. For a very short time the soil treated with 2 per cent sodium chloride leached readily, but it soon dropped to about one-third of the normal soil. The sodium-sulfate-treated soil leached more readily than did the untreated soil; whereas soil treated with sodium carbonate leached very slowly even at

TABLE 3

Recovery of salts from synthetic and natural alkali soils

SOIL	TREATMENT			NaCl RECOVERED		Na_2SO_4 RECOVERED		Na_2CO_3 RECOVERED	
	NaCl	Na_2SO_4	Na_2CO_3	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*
College	180			128.9	71.6				
		180				159.9	88.8		
			180					120.5	66.9
	90		90	85.0	94.5			22.0	24.5
	90	90		85.0	94.5	86.0	95.6		
		90	90			83.0	92.2	19.4	21.6
	60	60	60	54.8	91.3	58.6	97.7	26.0	43.3
Corinne				379.1		6.3			
Richland Acres				12.7		67.8			
Benson Ward				97.0		40.6		103.7	

first, and by the end of one year only 1 cc. an hour was passing through the soil. This soil and drain water soon became dark in color. The soil puddled greatly and shrank in volume so that it did not fill the containers. Apparently the granular structure had been broken down completely. Although the leaching was continued in the case of some of the soil for nearly two years, considerable of the salt still remained in the soil, as may be seen from the summarized results given in table 3.

From 71.6 to 94.5 per cent of the chlorides, from 88.8 to 97.7 per cent of the sulfates, and only 21.6 to 66.9 per cent of the carbonates were recovered. Hence, in not a single case had all of the added salt been recovered although leaching had been as complete as was feasible without preliminary treatment.

NUMBER OF BACTERIA

The number of bacteria were determined by plating on modified synthetic agar having the following composition:

1000 cc. of distilled water.
10 gm. dextrose
0.5 gm. dipotassium phosphate (K_2HPO_4)
0.2 gm. magnesium sulfate ($MgSO_4$)
20 gm. powdered agar-agar

Before sampling, all large masses were broken up and the soil was thoroughly mixed by shaking in the original container. One-hundred gram portions of the soil were weighed on sterile paper into 200 cc. of sterile water. This was shaken for one minute and 1 cc. of this suspension was transferred to 99 cc. of sterile water. The dilution was continued in 9 cc. of sterile water and plates were made so as to give dilutions of 1 to 20,000 and 1 to 200,000. They were incubated at 28°C. for seven days and then counted. Three sets of plates were made from each soil and the results averaged. Hence, each reported result represents six determinations made on the duplicate pots receiving the same treatment. The average results for the chloride-treated soil are given in table 4.

The determinations made in 1921 were on composite samples of the soil. The six pots in each series which had received the same treatment were sampled and composited.

The leaching of the normal soil increased the bacterial content 24 per cent. This could not have come from the organisms carried in by the leach water for two reasons: first, the same water was used in irrigating the unleached soil, hence, its effect would have been the same on the microflora of both leached and unleached soils, second, it could not have been due to the soil retaining the microörganisms of the water used in leaching, as ordinary tap water, which is piped from a mountain spring, was used and repeated counts of the water during the leaching never showed a bacterial content of over 30 to each cubic centimeter. The increase could be due to the water breaking up the clumps of bacteria within the soil, under which condition the increase would be only apparent; or it might be due to a chemical or physical action upon the soil or its constituents which renders it more suitable to bacterial growth. The water may have removed chemical or biological substances which are inimical to bacterial growth. That this entity is a bacteriophage is a feasible explanation.

The 2 per cent sodium chloride at the first sampling had reduced the bacterial numbers to 54 per cent normal, but after this soil was leached, they increased 50 per cent. This is 26 per cent above the normal leached soil. The combination of sodium chloride and sodium sulfate slightly increased the numbers. Leaching of this soil increased the numbers to about the same extent as leaching of the sodium-chloride-treated soil. The combination of sodium

chloride and sodium carbonate is more toxic than sodium chloride and sodium sulfate or sodium chloride alone. This soil when leached contained seven times as many bacteria as the normal soil. The combination of the three salts

TABLE 4

Colonies developing upon synthetic agar from soil with and without chlorides

TREATMENT	COLONIES DEVELOPING IN 7 DAYS		
	1921	July, 1922	August, 1923
	thousands	*thousands*	*thousands*
Untreated soil	2,573	3,300	2,250
Untreated soil leached	3,182	3,500	3,150
Untreated soil leached + 15 T. manure		3,150	5,150
Untreated soil leached + soil extract		3,100	6,100
Soil + 2 per cent NaCl	1,387	1,850	3,250
Soil + 2 per cent NaCl leached	3,870	2,700	4,650
Soil + 2 per cent NaCl + 15 T. manure		1,500	3,900
Soil + 2 per cent NaCl leached + 15 T. manure		4,550	4,450
Soil + 2 per cent NaCl + soil extract		600	2,450
Soil + 2 per cent NaCl leached + soil extract		5,650	6,350
Soil + 1 per cent each NaCl and Na_2SO_4	2,752	3,750	1,450
Soil + 1 per cent each NaCl and Na_2SO_4 leached	3,750	4,000	4,300
Soil + 1 per cent each NaCl and Na_2SO_4 leached + 15 T. manure		5,200	4,500
Soil + 1 per cent each NaCl and Na_2SO_4 leached + soil extract		4,150	1,850
Soil + 1 per cent each NaCl and Na_2CO_3	1,657	8,450	4,650
Soil + 1 per cent each NaCl and Na_2CO_3 leached	18,750	15,050	4,350
Soil + 1 per cent each NaCl and Na_2CO_3 leached + 15 T. manure		10,600	7,050
Soil + 1 per cent each NaCl and Na_2CO_3 leached + soil extract		12,850	3,650
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	3,042	10,250	2,600
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3, leached	7,200	9,450	2,650
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached + 15 T. manure		5,400	3,000
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached + soil extract		9,200	2,100
Corinne alkali soil	220	600	1,800
Corinne alkali soil + 15 T. manure		300	1,250
Corinne alkali soil leached	885	3,150	5,450
Corinne alkali soil leached + 15 T. manure		2,700	1,950
Corinne alkali soil leached + soil extract		7,050	3,550

stimulated, and when this was washed out the stimulation became even greater. The Corinne alkali soil contained fewer organisms than any of the synthetic alkali soils; there was only a quarter of a million whereas two years later there was nearly two millions—leaching increased the number 400 per cent.

The evidence is strong that this soil contains something which is limiting the number of bacteria within it, and that this limiting factor is removed by leaching or by small quantities of the alkali. The factor cannot be protozoa as they would not be washed from the soil as readily as the bacteria; it could be a filterable virus or a toxic product. It would have to be assumed that the virus is more readily washed from the soil than are the bacteria and that it is more sensitive to alkalies. It is readily conceivable that the limiting factor could be a bacterial poison which is removed by leaching, but it would have to be assumed that the various salts neutralize its toxicity. The bacterial numbers in the second sampling are usually higher than in the first or third. By using the normal unleached soil in each case as a basis, leaching may be seen to increase the bacterial numbers 20 per cent; leaching and manure, 140 per cent; and leaching the soil and soil extract, 67 per cent. Two per cent sodium chloride reduces the bacterial content to 92 per cent of normal, but leaching increases it to 30 per cent above normal. The manure, when applied to the soil containing sodium chloride, has little influence on numbers; but when applied to sodium-chloride-leached soil, increase the numbers 30 per cent over that receiving no manure. Soil extract applied to the alkali soil apparently retards, but applied to the leached soil, increases the numbers 41 per cent over the manure-treated soil. Similar relationships exist in the combinations of the salts, with the exception of the sodium carbonate. Here the manure and soil extract fail to increase the numbers.

Although large variations occur in the numbers, it is safe to conclude that with this soil, leaching increases the bacterial content. Two per cent sodium chloride greatly decreases the numbers, but a combination of the chloride with the sulfate or carbonate or with both increases the numbers. Judged by the number of bacteria developing on synthetic media, it would appear from these results that the extract from the fertile soil is just as effective in increasing the numbers of microörganisms as is barnyard manure.

The results for the sulfates are given in table 5. Judged from the number of microörganisms developing on synthetic media, sodium sulfate is not nearly so toxic as is sodium chloride, a conclusion which corresponds with the results obtained with the higher plants. The combination of sodium sulfate and sodium carbonate stimulates to an even greater extent than does the sodium-chloride-sodium-carbonate combination. Although the increase due to leaching is not so pronounced as it was in the sodium chloride treated soil, it unmistakably manifests itself.

The manure and soil extract when applied to the soil usually increase the bacterial numbers. In this regard the soil extract is again just as effective as is the organic manure.

The results for the carbonate are given in table 6.

Sodium carbonate is much more toxic than either of the other salts. Two per cent sodium chloride reduced the bacterial numbers 11 per cent and leaching increased them 38 per cent, as an average compared with the normal soil.

The average results for the sodium sulfate as compared with the normal soil are within experimental error. But the sodium carbonate treated soil shows a decrease of 24 per cent due to the carbonate and an increase of over 830 per

TABLE 5

Colonies developing upon synthetic agar from soil with and without sulfates

TREATMENT	COLONIES DEVELOPING IN 7 DAYS		
	1921	July, 1922	August, 1923
	thousands	*thousands*	*thousands*
Untreated soil	2,573	3,300	2,250
Untreated soil leached	3,182	3,500	3,150
Untreated soil leached + 15 T. manure		3,150	5,150
Untreated soil leached + soil extract		3,100	6,100
Soil + 2 per cent Na_2SO_4	3,605	2,350	2,200
Soil + 2 per cent Na_2SO_4 leached	3,970	2,450	2,250
Soil + 2 per cent Na_2SO_4 + 15 T. manure		3,300	1,750
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure		3,500	3,200
Soil + 2 per cent Na_2SO_4 + soil extract		3,800	2,300
Soil + 2 per cent Na_2SO_4 leached + soil extract		3,800	2,200
Soil + 1 per cent each Na_2SO_4 and NaCl	2,752	3,750	1,450
Soil + 1 per cent each Na_2SO_4 and NaCl leached	3,700	4,000	4,300
Soil + 1 per cent each Na_2SO_4 and NaCl leached + 15 T. manure		5,200	4,500
Soil + 1 per cent each Na_2SO_4 and NaCl leached + soil extract		4,150	4,850
Soil + 1 per cent each Na_2SO_4 and Na_2CO_3	1,745	16,650	1,300
Soil + 1 per cent each Na_2SO_4 and Na_2CO_3 leached	8,100	13,800	1,800
Soil + 1 per cent each Na_2SO_4 and Na_2CO_3 leached + 15 T. manure		19,500	2,200
Soil + 1 per cent each Na_2SO_4 + Na_2CO_3 leached + soil extract		7,700	1,850
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3	3,042	10,250	2,600
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached	7,200	9,450	2,650
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + 15 T. manure		5,400	3,000
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + soil extract		9,200	2,100
Richland acre alkali soil	1,452	6,000	3,550
Richland acre alkali soil + 15 T. manure		14,550	2,200
Richland acre alkali soil leached	1,722	5,050	3,000
Richland acre alkali soil leached + 15 T. manure		2,600	5,000
Richland acre alkali soil leached + soil extract		3,500	2,000

cent due to the leaching. Hence, the numbers increase enormously after the salt is removed. This is surprising, for the soil after leaching is in very poor physical condition. Moreover, much of the organic matter and large quantities of the nitrogen have been removed. The readily available phosphorus

and potassium had been rendered soluble and leached from the soil (6). Hence, it would appear that both physical and chemical conditions have been left less favorable for bacterial multiplication, yet the bacterial numbers greatly

TABLE 6

Colonies developing upon synthetic agar from soil with and without carbonates

TREATMENT	COLONIES DEVELOPING IN 7 DAYS		
	1921	July, 1922	August, 1923
	thousands	*thousands*	*thousands*
Untreated soil	2,573	3,300	2,250
Soil leached	3,182	3,500	3,150
Soil leached + 15 T. manure		3,150	5,150
Soil leached + soil extract		3,100	6,100
Soil + 2 per cent Na_2CO_3	982	3,750	1,450
Soil + 2 per cent Na_2CO_3 leached	11,000	10,650	3,550
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure		18,250	2,600
Soil + 2 per cent Na_2CO_3 + 15 T. manure		5,100	2,050
Soil + 2 per cent Na_2CO_3 + soil extract		5,050	800
Soil + 2 per cent Na_2CO_3 leached + soil extract		15,000	4,300
Soil + 1 per cent each Na_2CO_3, NaCl	1,657	8,450	4,650
Soil + 1 per cent each Na_2CO_3, NaCl leached	18,750	15,050	4,350
Soil + 1 per cent each Na_2CO_3, NaCl leached + 15 T. manure		10,600	7,050
Soil + 1 per cent each Na_2CO_3, NaCl leached + soil extract		12,850	3,650
Soil + 1 per cent each Na_2CO_3, and Na_2SO_4	1,745	16,650	1,300
Soil + 1 per cent each Na_2CO_3, and Na_2SO_4 leached	8,100	13,800	1,800
Soil + 1 per cent each Na_2CO_3, and Na_2SO_4 leached + 15 T. manure		19,500	2,200
Soil + 1 per cent each Na_2CO_3, and Na_2SO_4 leached + soil extract		7,700	1,850
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4	3,042	10,250	2,600
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4 leached	7,200	9,450	2,650
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4 leached + 15 T. manure		5,400	3,000
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4 leached + soil extract		9,200	2,100
Benson alkali soil	40	610	150
Benson alkali soil + 15 T. manure		645	1,550
Benson alkali soil leached	267	1,755	2,100
Benson alkali soil leached + 15 T. manure		1,020	3,750
Benson alkali soil + soil extract		840	550
Benson alkali soil leached + soil extract		1570	2,500

increase. The most plausible explanation seems to be that there is within the soil some biological factor that is rendered inactive by the alkali, and when part of the alkali is removed by leaching, the bacteria multiply unhindered.

Moreover, all of the salt treatments give a great reduction at first, but after a time the number of organisms in the alkali treated soil becomes more numerous. This raises the very important question: Do the normal species develop into alkali resistant strains or is a different microflora developing within the soil? This must be answered by future work.

AMMONIFICATION

The ammonifying power of the soil was determined by weighing 100-gm. portions of the soil and 2 gm. of dried blood into sterile tumblers and covering them with petri dishes. The dried blood was thoroughly mixed with the soil by means of a sterile spatula and the water content made up to 18 per cent with sterile distilled water. The samples were incubated at 28° to 30°C. for 4 days and the ammonia was determined by transferring them to Kjeldahl flasks with 250 cc. of distilled water, adding 2 gm. of magnesium oxide, and distilling into 0.1*N* sulfuric acid. The determinations were all made in triplicate and compared with sterile blanks. Hence, each reported result represents the average of six determinations made on the duplicate pots. The average results for the chloride-treated soil, stated as milligrams of ammonia, recovered from 100 gm. of soil are given in table 7.

The leaching of the normal soil increased its ammonifying powers 12 per cent. The stimulation is greatest at the time of the first sampling and had not fully disappeared at the end of two years. The manure produced no measurable effect the first year, but the second year there was a gain in ammonia. The soil extract had no effect on the non-alkali soil.

Two per cent sodium chloride reduced ammonification to 10 per cent of normal. The addition of manure or soil extract to the unleached soil had no influence. Leaching the soil brought it back to 85 per cent of normal, and the addition of manure to the leached soil restored it to its normal ammonifying efficiency. The soil extract was not as effective in this regard as was the manure.

A mixture of sodium chloride and sodim sulfate is less toxic, measured in terms of ammonification, than is sodium chloride alone. Moreover, the leaching restores such a soil to its original ammonifying powers. The addition of soil extract or manure raises its ammonifying powers above the normal. Here also the manure is more efficient than is the soil extract.

The mixture of sodium chloride and sodium carbonate is not as toxic as is the single salt; moreover, such a soil is more easily restored to its normal ammonifying powers. In restoring ammonifying efficiency soil extract and manure are about equally efficient.

A mixture of the three salts is slightly more toxic than the two. Neither leaching, soil extract, nor manure, when used singly or in combination, fully restored the ammonifying powers of the soil.

The Corinne alkali soil produced very little ammonia. The manure and soil extract were both without effect on the unleached soil. The leaching of the soil increased its ammonifying powers, which were still less than one-half

those of the non-alkali soil. At the end of two years neither manure nor soil extract had brought this soil up to a normal ammonifying efficiency. But the leached soil in the absence of treatment did not greatly increase in ammo-

TABLE 7

Ammonia found in soil with and without sodium chloride after 4 days' incubation

TREATMENT	AMOUNT OF AMMONIA FOUND		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	89	91	66
Soil leached	107	96	74
Soil leached + 15 T. manure		97	103
Soil leached + soil extract		90	81
Soil + 2 per cent NaCl	10	8	9
Soil + 2 per cent NaCl leached	65	59	84
Soil + 2 per cent NaCl + 15 T. manure		9	9
Soil + 2 per cent NaCl leached + 15 T. manure		73	114
Soil + 2 per cent NaCl + soil extract		9	13
Soil + 2 per cent NaCl leached + soil extract		66	69
Soil + 1 per cent each NaCl, Na_2SO_4	15	8	31
Soil + 1 per cent each NaCl, Na_2SO_4 leached	94	106	74
Soil + 1 per cent each NaCl, Na_2SO_4 leached + 15 T. manure		150	102
Soil + 1 per cent each NaCl, Na_2SO_4 leached + soil extract		112	83
Soil + 1 per cent each NaCl, Na_2CO_3	45	22	32
Soil + 1 per cent each NaCl, Na_2CO_3 leached	70	49	118
Soil + 1 per cent each NaCl, Na_2CO_3 leached + 15 T. manure		70	113
Soil + 1 per cent each NaCl, Na_2CO_3 leached + soil extract		73	118
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	19	10	34
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached	64	67	73
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached + 15 T. manure		58	103
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached + soil extract		62	70
Corinne alkali soil	2	2	5
Corinne alkali soil + 15 T. manure		1	6
Corinne alkali soil leached	40	16	57
Corinne alkali soil leached + 15 T. manure		32	89
Corinne alkali soil + soil extract		1	7
Corinne alkali soil leached + soil extract		12	96

nifying efficiency during the two years. In restoring the ammonifying powers of the soil, the soil extract was just as efficient as was the manure. The results indicate that one of the greatest benefits derived from the manure was the reseeding of the soil with an appropriate microflora.

The results for the sulfates are given in table 8.

From the viewpoint of ammonification, sulfates evidently are not as toxic as are chlorides. Such a soil is more easily reclaimed, the mere leaching of the

TABLE 8

Ammonia found in soil with and without sodium sulfate after 4 days' incubation

TREATMENT	AMOUNT OF AMMONIA FOUND		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	89	91	66
Soil leached	107	96	74
Soil leached + 15 T. manure		97	103
Soil leached + soil extract		90	81
Soil + 2 per cent Na_2SO_4	22	43	63
Soil + 2 per cent Na_2SO_4 leached	93	93	80
Soil + 2 per cent Na_2SO_4 + 15 T. manure		47	73
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure		118	113
Soil + 2 per cent Na_2SO_4 + soil extract		36	45
Soil + 2 per cent Na_2SO_4 leached + soil extract		105	38
Soil + 1 per cent each Na_2SO_4, NaCl	15	8	31
Soil + 1 per cent each Na_2SO_4, NaCl leached	94	106	74
Soil + 1 per cent each Na_2SO_4, NaCl leached + 15 T. manure		150	102
Soil + 1 per cent each Na_2SO_4, NaCl leached + soil extract		112	83
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	51	45	69
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	103	63	109
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + 15 T. manure		69	130
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + soil extract		58	103
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3	19	9	34
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached	64	67	73
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + 15 T. manure		58	103
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + soil extract		62	70
Richland acre alkali soil	11	11	50
Richland acre alkali soil + 15 T. manure		38	70
Richland acre alkali soil leached	24	29	66
Richland acre alkali soil leached + 15 T. manure		32	86
Richland acre alkali soil + soil extract		10	57
Richland acre alkali soil leached + soil extract		24	42

soil being sufficient to restore it to normal. Both the soil extract and the manure bring the leached soil to above normal. Moreover, the addition of the manure to the unleached soil is sufficient in some cases to restore the soil

to its normal ammonifying powers. This of course, is only temporary, and as the organic matter decays, the toxic properties of the salts reappear.

TABLE 9

Ammonia found in soil with and without sodium carbonate after 4 days' incubation

TREATMENT	AMOUNT OF AMMONIA		
	1921	July, 1922	August, 1923
	mgm.	mgm.	mgm.
Untreated soil	89.0	91.0	66.0
Soil leached	107.0	96.0	74.0
Soil leached + 15 T. manure		97.0	103.0
Soil leached + soil extract		90.0	81.0
Soil + 2 per cent Na_2CO_3	22.4	46.4	32.8
Soil + 2 per cent Na_2CO_3 leached	92.8	93.0	77.5
Soil + 2 per cent Na_2CO_3 + 15 T. manure		46.8	73.4
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure		118.9	112.5
Soil + 2 per cent Na_2CO_3 + soil extract		35.9	42.7
Soil + 2 per cent Na_2CO_3 leached + soil extract		100.2	115.0
Soil + 1 per cent each Na_2CO_3, NaCl	15.0	8.0	31.0
Soil + 1 per cent each Na_2CO_3, NaCl leached	94.0	106.0	74.0
Soil + 1 per cent each Na_2CO_3, NaCl leached + 15 T. manure		150.0	102.0
Soil + 1 per cent each Na_2CO_3, NaCl leached + soil extract		112.0	83.0
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	51.0	45.0	69.0
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	103.0	63.0	109.0
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + 15 T. manure		69.0	130.0
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + soil extract		58.0	103.0
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3	19.0	9.0	34.0
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached	64.0	67.0	73.0
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + 15 T. manure		58.0	103.0
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + soil extract		62.0	70.0
Benson alkali soil	8.8	10.7	12.7
Benson alkali soil + 15 T. manure		24.0	16.5
Benson alkali soil leached	46.5	52.5	93.4
Benson alkali soil leached + 15 T. manure		69.7	122.7
Benson alkali soil + soil extract		8.2	12.4
Benson alkali soil leached + soil extract		52.2	107.1

The results are significant in that they are in keeping with those obtained when the plant is taken as the index. Moreover, it is the common experience that the sulfate alkali soil is more readily reclaimed than is the chloride. The natural alkali soil has a lower ammonifying power than has the artificially

produced, and is harder to reclaim. The artificial soil of this series is restored by leaching, but it requires both leaching and re-inoculation to restore the natural soil.

The results for the carbonates are given in table 9.

Sodium carbonate is more toxic to ammonifiers than is sodium sulfate, but is less toxic than is sodium chloride—2 per cent sodium chloride reduced ammonification to 10 per cent of normal, sodium carbonate to 41 per cent of normal, and sodium sulfate to 52 per cent of normal. Moreover, it is more easily returned to its normal ammonifying power than is the sodium chloride carrying soil. Both manure and soil extract are efficient in reseeding the leached soil. Moreover, it is interesting to note that the leached manure-treated soils shows a high ammonifying power, the alkali having a stimulating influence. All of these results are in direct accord with the results which were obtained by mixing the salt directly with the soil and then incubating (3).

NITRIFICATION

The nitrifying power of the soil was determined similarly to the ammonifying power, except that the samples in the former case were incubated for 21 days. The moisture content was made up weekly to the initial percentage and the nitric nitrogen determined as outlined elsewhere (5). The average results for the chloride-treated soil are given in table 10.

The leaching of the soil increased nitrification 8 per cent. Hence, we find that the leaching of this fertile soil has increased the numbers, ammonification, and nitrification, thus showing that the water must remove some limiting factor in the bacterial growth in this soil. The addition of manure increases, whereas the addition of the soil extract decreases, nitrification.

Two per cent of sodium chloride reduces nitrification to 12 per cent of normal. Both manure and soil extract are valueless when judged by nitrification. However, the soil extract is more valuable than is the manure in restoring nitrification in the leached soil.

As it is only after the soil has been leached and re-inoculated that nitrification is normal, these results would point to the conclusion that 2 per cent sodium chloride in a soil for some time not only inactivates the nitrifying organisms but actually destroys them. A combination of the two salts is just as toxic as is the single salt. The combination of the three salts is toxic at first but later decreases. Whether this is due to a chemical combination of the salts with soil constituents or whether the organisms become accustomed to the alkali salts cannot be decided from these results. They point to the conclusion that alkali soil after leaching must be reseeded with the nitrifying organisms before high nitrification occurs. This may be accomplished by chance inoculation, which requires considerable time and is uncertain, or by the use of soil or barnyard manure. The latter not only carries the desired organisms but also improves the physical conditions.

During the first year, the sulfates are just as toxic as are the chlorides, with sulfates, the toxicity decreases during the second and third year even where no treatment has been given to the soil. This raises the interesting

TABLE 10

Nitric nitrogen produced in 100 gm. of soil during 21 days' incubation with and without sodium chloride

TREATMENT	AMOUNT OF NITRIC NITROGEN FOUND		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	40.6	56.3	53.2
Soil leached	46.2	53.9	62.0
Soil leached + 15 T. manure		53.2	109.5
Soil leached + soil extract		43.8	45.5
Soil + 2 per cent NaCl	5.6	9.5	15.7
Soil + 2 per cent NaCl leached	31.5	41.6	50.4
Soil + 2 per cent NaCl + 15 T. manure		1.4	15.5
Soil + 2 per cent NaCl leached + 15 T. manure		37.1	35.7
Soil + 2 per cent NaCl + soil extract		1.1	4.2
Soil + 2 per cent NaCl leached + soil extract		54.2	60.2
Soil + 1 per cent each NaCl, Na_2SO_4	1.4	9.8	5.2
Soil + 1 per cent each NaCl, Na_2SO_4 leached	41.3	66.5	56.5
Soil + 1 per cent each NaCl, Na_2SO_4 leached + 15 T. manure		42.4	100.5
Soil + 1 per cent each NaCl, Na_2SO_4 leached + soil extract		47.6	49.5
Soil + 1 per cent each NaCl, Na_2CO_3,	4.9	4.5	7.7
Soil + 1 per cent each NaCl, Na_2CO_3, leached	2.8	3.5	3.5
Soil + 1 per cent each NaCl, Na_2CO_3, leached + 15 T. manure		4.2	21.0
Soil + 1 per cent each NaCl, Na_2CO_3 leached + soil extract		2.8	2.8
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3,	1.4	33.5	23.8
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3, leached	46.9	64.7	87.2
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3, leached + 15 T. manure		74.2	72.8
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached + soil extract		73.2	59.6
Corinne alkali soil	4.9	2.8	7.0
Corinne alkali soil + 15 T. manure		3.2	4.2
Corinne alkali soil leached	2.1	13.3	7.7
Corinne alkali soil leached + 15 T. manure		13.8	38.5
Corinne alkali soil + soil extract		1.4	3.8
Corrine alkali soil leached + soil extract		12.0	12.6

question: Has there developed within the soil an alkali-resistant strain of the nitrifiers? The mere leaching of the soil restores completely its nitrifying power, a thing which does not occur in the case of the chloride-carrying soil.

The addition of the soil extract has little value. This would be expected where the concentration of the alkali is not sufficient to destroy the nitrifying microflora. However, manure has a marked accelerating influence upon the

TABLE 11

Nitric nitrogen produced in 100 gm. of soil during 21 days' incubation with and without sulfates

TREATMENT	AMOUNT OF NITRIC NITROGEN FOUND		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	40.6	56.3	53.2
Soil leached	46.2	53.9	62.0
Soil leached + 15 T. manure		53.2	109.5
Soil leached + soil extract		43.8	45.5
Soil + 2 per cent Na_2SO_4	1.4	21.0	47.6
Soil + 2 per cent Na_2SO_4 leached	47.6	41.3	56.0
Soil + 2 per cent Na_2SO_4 + 15 T. manure		56.0	14.3
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure		63.0	98.7
Soil + 2 per cent Na_2SO_4 + soil extract		21.7	29.7
Soil + 2 per cent Na_2SO_4 leached + soil extract		52.8	47.2
Soil + 1 per cent each Na_2SO_4, NaCl	1.4	9.8	5.2
Soil + 1 per cent each Na_2SO_4, NaCl leached	41.3	66.5	56.5
Soil + 1 per cent each Na_2SO_4, NaCl leached + 15 T. manure		42.4	100.5
Soil + 1 per cent each Na_2SO_4, NaCl leached + soil extract		47.6	49.5
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	4.2	3.2	4.8
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	1.7	2.8	3.5
Soil + 1 per cent each Na_2SO_4, Na_2CO_3, leached + 15 T. manure		4.9	7.7
Soil + 1 per cent each Na_2SO_4, Na_2CO_3, leached + soil extract		40.9	1.4
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3	1.4	33.5	23.8
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached	46.9	64.7	87.2
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + 15 T. manure		74.2	72.8
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + soil extract		73.2	59.6
Richland acre alkali soil	9.1	17.5	16.0
Richland acre alkali soil + 15 T. manure		7.0	27.0
Richland acre alkali soil leached	5.9	10.9	19.3
Richland acre alkali soil leached + 15 T. manure		6.0	26.9
Richland acre alkali soil + soil extract		25.2	11.2
Richland acre alkali soil leached + soil extract		13.7	10.8

nitrifying powers which probably comes from the improved physical condition of the soil, as it is apparent that aëration is much better in the manured than in the unmanured soil.

Sodium carbonate is more toxic when measured in terms of nitrification

than is either the chloride or the sulfate. The carbonate reduced nitrification to 7 per cent normal, the chloride to 12 per cent normal, and the sulfate to 47 per cent normal.

The percentage reduction of ammonification and nitrification for chlorides and sulfates is not far different, but the reduction of nitrification is much more pronounced in the presence of carbonates than is the reduction of ammonification. There are probably two factors involved: 1. Probably the nitrifying organisms are more sensitive to sodium carbonate than are the ammonifiers. 2. The nitrifying process is strictly aerobic, whereas ammonification may proceed under either aerobic or anaerobic conditions, and soil which contains sodium carbonate is in a very poor state of tilth.

Even after leaching, the soil shows very low nitrifying power. Neither the soil extract nor the manure is effective in restoring nitrification. It is evident that the soil must have some preliminary treatment before leaching and afterwards receive soil and manure—the first to inoculate, the second to improve tilth.

NITROGEN FIXATION

The nitrogen-fixing power of the soil was determined by the tumbler method. One-hundred-gram portions of the soil were weighed into sterile, covered tumblers. To each of these was added 1.5 gm. of lactose. This was carefully mixed and sufficient sterile distilled water added to bring the moisture up to 18 per cent. Each soil together with sterile blanks was incubated for 21 days at 28 to 30°C. after which the nitrogen was determined by the Gunning method revised to include nitrates (5). In every case four or more determinations were made on the soil from each pot. Hence, the results as given in the tables are the averages of eight determinations made on two similarly treated pots. In table 13 the results are given for the sodium-chloride-treated soil.

The direct leaching of the untreated soil has no measurable influence on the nitrogen-fixing power of the soil. The soil which had received 2 per cent sodium chloride and which was then leached showed increased nitrogen-fixing power. This is also true where the mixture of salts had been leached from the soil. The only fact which appears clear from these results is that the alkali-leached soil gains more rapidly in nitrogen when incubated than the untreated or alkali-containing soil. There is no evidence that the nitrogen fixers had been destroyed in the synthetic soils by the alkalies, as with one exception no benefit was derived from the use of manure or soil extract.

On the contrary, in the natural Corinne alkali soil, no gains of nitrogen were noted until this soil had been inoculated with soil extract containing the azotobacter.

The determination made in 1921 showed a loss of nitrogen in the sodium-sulfate-treated soil. In every determination made later the alkali-containing and the leached soil showed unmistakable evidence of gains in nitrogen. This is true in both the natural and synthetic alkali soil. There is no evidence that

the soil extract or manure is beneficial. It is evident that the nitrogen fixers survive this concentration of alkali, and when the salt is removed function more rapidly than they did before, probably on account of the absence of

TABLE 12

Nitric nitrogen produced in 100 gm. of soil during 21 days' incubation with and without sodium carbonate

TREATMENT	AMOUNT OF NITRIC NITROGEN FORMED		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	40.6	56.3	53.2
Soil leached	46.2	53.9	62.0
Soil leached + 15 T. manure		53.2	109.5
Soil leached + soil extract		43.8	45.5
Soil + 2 per cent Na_2CO_3	6.3	0.7	3.5
Soil + 2 per cent Na_2CO_3 leached	2.1	2.4	3.2
Soil + 2 per cent Na_2CO_3 + 15 T. manure		1.4	1.7
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure		3.5	1.4
Soil + 2 per cent Na_2CO_3 + soil extract		1.4	2.5
Soil + 2 per cent Na_2CO_3 leached + soil extract		4.5	1.7
Soil + 1 per cent each Na_2CO_3, NaCl	4.9	4.5	7.7
Soil + 1 per cent each Na_2CO_3, NaCl leached	2.8	3.5	3.5
Soil + 1 per cent each Na_2CO_3, NaCl leached + 15 T. manure		4.2	21.0
Soil + 1 per cent each Na_2CO_3, NaCl leached + soi extract		2.8	2.8
Soil + 1 per cent each Na_2CO_3, Na_2SO_4	4.2	3.2	4.8
Soil + 1 per cent each Na_2CO_3, Na_2SO_4, leached	1.7	2.8	3.5
Soil + 1 per cent each Na_2CO_3, Na_2SO_4, leached + 15 T. manure		4.9	7.7
Soil + 1 per cent each Na_2CO_3, Na_2SO_4 leached + soil extract		40.9	1.4
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4 + NaCl	1.4	33.5	23.8
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4 + NaCl leached.	46.9	64.7	87.2
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4 + NaCl leached. + 15 T. manure		74.2	72.8
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4 leached + soil extract		73.2	59.6
Benson alkali soil	2.8	1.7	1.7
Benson alkali soil + 15 T. manure		2.4	1.0
Benson alkali soil leached	2.4	4.9	1.4
Benson alkali soil leached + 15 T. manure		1.7	2.8
Bensoil alkali soil + soil extract		1.1	4.5
Benson alkali soil leached and soil extract		1.1	3.2

competitive microorganisms. The results for the carbonates are given in table 15.

The sodium-carbonate-treated soil loses nitrogen about to the same extent

as the original soil, but when manure is added to such a soil the loss becomes very great, indicating a very perceptible denitrification. Such a soil, however, after being leached, although only 24 per cent of the carbonates had been

TABLE 13

Nitrogen fixed during 21 days in 100 gm. of soil to which had been added 1.5 per cent lactose with and without sodium chloride treatment

TREATMENT	AMOUNT OF NITROGEN FIXED		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	−6.3	−0.8	10.5
Soil leached	0.0	−12.4	2.3
Soil leached + 15 T. manure		−4.4	3.5
Soil leached + soil extract		−9.6	3.2
Soil + 2 per cent NaCl	−5.6	1.4	−4.4
Soil + 2 per cent NaCl leached	2.8	4.2	2.3
Soil + 2 per cent NaCl + 15 T. manure		−16.4	−5.8
Soil + 2 per cent NaCl leached + 15 T. manure		−2.3	10.3
Soil + 2 per cent NaCl + soil extract		−8.5	−5.1
Soil + 2 per cent NaCl leached + soil extract		−9.2	−1.0
Soil + 1 per cent each NaCl, Na_2SO_4	7.0	−4.2	12.4
Soil + 1 per cent each NaCl, Na_2SO_4 leached	9.8	1.1	6.5
Soil + 1 per cent each NaCl, Na_2SO_4 leached + 15 T. manure		−2.0	−1.4
Soil + 1 per cent each NaCl, Na_2SO_4 + soil extract		−0.1	3.3
Soil + 1 per cent each NaCl, Na_2CO_3	5.6	−0.2	−3.3
Soil + 1 per cent each NaCl, Na_2CO_3 leached	11.2	5.8	8.9
Soil + 1 per cent each NaCl, Na_2CO_3 leached + 15 T. manure		13.8	5.1
Soil + 1 per cent each NaCl, Na_2CO_3 leached + soil extract		3.6	1.8
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	2.8	2.8	0.7
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached	10.0	3.3	1.1
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 + 15 T. manure		5.5	7.3
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 + soil extract		5.5	5.9
Corinne alkali soil	4.1	0.9	1.8
Corinne alkali soil + 15 T. manure		−0.3	4.2
Corinne alkali soil leached	0.0	−1.8	0.3
Corinne alkali soil leached + 15 T. manure		−2.6	0.3
Corinne alkali soil + soil extract		9.9	22.1
Corinne alkali soil leached + soil extract		1.4	1.0

removed, fixed marked quantities of nitrogen. This is also true in the natural alkali soil, in which sodium carbonate has been present for years. It is evident from these results that the nitrogen-fixing organisms are very resistant to alkali, as was earlier found by the direct tumbler method (4).

In order to obtain more definite information on this subject, leached and

unleached soils were inoculated into 100 cc. of Ashby solution, incubated 21 days, and the nitrogen was determined. The average results of eight determinations made in 1923 are given in table 16.

TABLE 14

Nitrogen fixed during 21 days in 100 gm. of soil to which had been added 1.5 per cent lactose with and without sulfates

TREATMENT	AMOUNT OF NITROGEN FIXED		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated	−6.3	−0.8	10.5
Soil leached	0.0	−12.4	2.3
Soil leached + 15 T. manure		−4.4	3.5
Soil leached + soil extract		−9.6	3.2
Soil + 2 per cent Na_2SO_4	−5.6	3.4	3.8
Soil + 2 per cent Na_2SO_4 leached	5.6	2.6	0.7
Soil + 2 per cent Na_2SO_4 + 15 T. manure		6.1	0.5
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure		5.7	4.8
Soil + 2 per cent Na_2SO_4 + soil extract		6.0	1.4
Soil + 2 per cent Na_2SO_4 leached + soil extract		2.0	2.8
Soil + 1 per cent each Na_2SO_4, NaCl	7.0	−4.2	12.4
Soil + 1 per cent each Na_2SO_4, NaCl leached	9.8	1.1	6.5
Soil + 1 per cent each Na_2SO_4, NaCl leached + 15 T. manure		−2.0	−1.4
Soil + 1 per cent each Na_2SO_4, NaCl leached + soil extract		−0.1	3.3
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	0.7	−0.9	−6.6
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	1.4	7.7	13.3
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + 15 T. manure		−0.6	8.3
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + soil extract		5.2	3.4
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3	2.8	2.8	0.7
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached	10.0	3.3	1.1
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + 15 T. manure		5.5	7.3
Soil + 0.66 per cent each Na_2SO_4, NaCl, Na_2CO_3 leached + soil extract		5.5	5.9
Richland acre alkali soil		3.9	8.3
Richland acre alkali soil + 15 T. manure		1.9	7.9
Richland acre alkali soil leached		6.1	4.2
Richland acre alkali soil leached + 15 T. manure		1.1	7.4
Richland acre alkali soil + soil extract		3.4	7.2
Richland acre alkali soil leached + soil extract		1.8	8.6

All of these soils when seeded into Asby solution fixed measurable quantities of nitrogen, thus substantiating the conclusion previously published (3), that the nitrogen-fixing organisms are much more resistant to soil alkalies than

are either the ammonifiers or nitrifiers. The results are more concordant with the solution than with the soil. It is significant that the leached soil invariably fixes more nitrogen than does the unleached soil. The fixation in the untreated

TABLE 15

Nitrogen fixed during 21 days in 100 gm. of soil to which had been added 1.5 per cent lactose with and without sodium carbonate

TREATMENT	AMOUNT OF NITROGEN FIXED		
	1921	July, 1922	August, 1923
	mgm.	*mgm.*	*mgm.*
Untreated soil	−6.3	−0.8	10.5
Soil leached	0.0	−12.4	2.3
Soil leached + 15 T. manure		−4.4	3.5
Soil leached + soil extract		−9.6	3.2
Soil + 2 per cent Na_2CO_3		−4.8	−1.0
Soil + 2 per cent Na_2CO_3 leached		4.3	4.2
Soil + 2 per cent Na_2CO_3 + 15 T. manure		−31.0	−5.2
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure		3.6	8.3
Soil + 2 per cent Na_2CO_3 + soil extract		−1.8	2.8
Soil + 2 per cent Na_2CO_3 leached + soil extract		1.8	1.4
Soil + 1 per cent each Na_2CO_3, NaCl	5.6	−0.2	−3.3
Soil + 1 per cent each Na_2CO_3, NaCl leached	11.2	5.8	8.9
Soil + 1 per cent each Na_2CO_3, NaCl leached + 15 T. manure		13.8	5.1
Soil + 1 per cent each Na_2CO_3, NaCl leached + soil extract		3.6	1.8
Soil + 1 per cent each Na_2CO_3, Na_2SO_4	0.7	−0.9	−6.6
Soil + 1 per cent each Na_2CO_3, Na_2SO_4 leached	1.4	7.7	13.3
Soil + 1 per cent each Na_2CO_3, Na_2SO_4 leached + 15 T. manure		−0.6	8.3
Soil + 1 per cent each Na_2CO_3, Na_2SO_4 leached + soil extract		5.2	3.4
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4	2.8	2.8	0.7
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4 leached	10.0	3.3	1.1
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4 leached + 15 T. manure		5.5	7.3
Soil + 0.66 per cent each Na_2CO_3, NaCl, Na_2SO_4 leached + soil extract		5.5	5.9
Benson alkali soil		−0.9	−0.8
Benson alkali soil + 15 T. manure		−4.8	−2.3
Benson alkali soil leached		5.1	3.6
Benson alkali soil leached + 15 T. manure		11.0	7.0
Benson alkali soil + soil extract		0.4	0.9
Benson alkali soil leached + soil extract		5.1	3.6

and in the sodium-sulfate-treated leached soil is greater than in the natural soil. The fixation in the carbonate-containing soil is low but the results point clearly to the conclusion that nitrogen fixers survive this concentration of

alkali. Even the native alkali soil, in which the salts had been present for years readily induced nitrogen fixation after leaching.

Characteristic azotobacter films occurred in Ashby solutions inoculated with leached and non-leached normal soil, in leached soil which had contained sodium sulfate, and in the natural sodium sulfate soil (Richland acre soil). In fact, the membrane formed earlier and was darker in the presence of sodium sulfate than in its absence. The azotobacter was recovered from the solutions producing typical membranes. Thus far the author has failed to recover azotobacter from the other soils. Hence the question arises: What are the

TABLE 16

Nitrogen fixed in 100 cc. Ashby solution in 21 days. Inoculated with 1 gm. soil, spring 1924

TREATMENT	AMOUNT OF NITROGEN FIXED	EXCESS FIXED BY LEACHED
	mgm.	*mgm.*
Soil untreated	8.38	
Soil leached	10.03	1.92
Soil + 2 per cent NaCl	4.67	
Soil + 2 per cent NaCl leached	8.12	3.45
Soil + 2 per cent Na_2SO_4	6.39	
Soil + 2 per cent Na_2SO_4 leached	9.61	3.22
Soil + 2 per cent Na_2CO_3	1.11	
Soil + 2 per cent Na_2CO_3 leached	3.36	2.25
Soil + 1 per cent each NaCl, Na_2SO_4	5.51	
Soil + 1 per cent each NaCl, Na_2SO_4 leached	6.15	0.64
Soil + 1 per cent each NaCl Na_2SO_4	5.51	
Soil + 1 per cent each NaCl, Na_2SO_4 leached	7.33	1.82
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	5.83	
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	8.49	2.66
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	6.07	
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached	6.21	0.14
Corinne alkali soil	1.40	
Corinne alkali soil leached	1.42	0.02
Richland acre alkali soil	4.62	
Richland acre alkali soil leached	4.39	−0.23
Benson alkali soil	0.51	
Benson alkali soil leached	3.76	3.25

organisms which are fixing nitrogen in these salt-containing soils? Is it possible that the anaerobic species *Clostridium* play an important rôle?

In table 17 is given the percentage loss or gain of nitrogen from the various soils. The total nitrogen was determined in the soil of each pot at the end of the leaching period. This in each case was taken as 100. The total nitrogen was redetermined at the end of two years. In the first column is given the percentage loss or gain from the specific soil during the two years; in the second column is given the total nitrogen removed in the crop; and in the third is given the gross percentage gain or loss of nitrogen. In interpreting these results one

must remember that one crop was the legume, crimson clover. Nodules wer found on the clover grown on the untreated soil, on all of the soil which had received the soil extract, and on all of the soil containing the sulfates. In other words, the legume organisms were proved to be present in all of the soils which yielded positive tests for azotobacter.

The untreated soil lost nearly ten per cent of its nitrogen, and even after allowance has been made for the nitrogen removed in the plant there is still a loss of 2.47 per cent of the total nitrogen. This is not experimental error, as

TABLE 17

Loss or gain of total nitrogen in pot

TREATMENT	LOSS OR GAIN OF TOTAL N DURING 2 YEARS	TOTAL N REMOVED IN 2 CROPS	N RECOVERED AT END OF 2 YEARS IN SOIL AND CROP
	per cent	*per cent*	*per cent*
Soil untreated	−9.50	98.1	−2.47
Soil leached no alkali	−3.27	153.0	8.42
Soil + 2 per cent NaCl	5.07		5.07
Soil + 2 per cent NaCl leached	−2.90	99.9	5.35
Soil + 2 per cent Na_2SO_4	5.66	8.1	6.29
Soil + 2 per cent Na_2SO_4 leached	2.07	75.6	8.52
Soil + 2 per cent Na_2CO_3	−17.98		−17.98
Soil + 2 per cent Na_2CO_3 leached	0.99	4.5	1.51
Soil + 1 per cent each NaCl, Na_2SO_4	0.66		0.66
Soil + 1 per cent each NaCl Na_2SO_4 leached	2.52	65.6	9.17
Soil + 1 per cent each NaCl, Na_2CO_3	6.90		6.90
Soil + 1 per cent each NaCl, Na_2CO_3 leached	3.57	6.4	4.32
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	3.63		3.63
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	−9.23	5.6	−8.62
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	7.22		7.22
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 leached	15.27	24.0	12.81
Corinne alkali soil	7.07		7.07
Corinne alkali soil leached	17.77	10.8	18.77
Richland acre soil	2.77	0.9	2.80
Richland acre soil leached	11.09	0.9	11.12
Benson alkali soil	2.61		2.61
Benson alkali soil leached	34.53	5.4	36.30

each sampling was thorough, and represented the nitrogen in thes oil. Moreover it manifested itself in the duplicate pots and would have to be recorded as an unknown loss, possibly denitrification. Only two other soils showed a loss, the one receiving sodium carbonate and the one receiving a mixture of sodium carbonate and sodium sulfate. In all but two cases the leached soil gained in nitrogen faster than did the unleached and in the case of the native alkali soil the gain was great.

In table 18 is given an inventory of the nitrogen of the various soils, calculated as pounds per acre.

Every soil except three registered a gain in total nitrogen, and all except five showed an actual gain in the soil. The leached in nearly every case made greater gains than did the unleached. The soil in which there was a mixture of the three salts gained more than did any of the other soils. The native alkali soil when leached, gained nitrogen rapidly. This was greatest where the predominating alkali was sodium carbonate and least where it was sodium sulfate. These results are significant in showing that alkali does actually

TABLE 18

Weight of total nitrogen in each acre

TREATMENT	AFTER LEACHING	LOSS THROUGH LEACHING		TOTAL LOSS OR GAIN FROM SOIL DURING 2 YEARS
		By difference	Calculated from recovered N	
	pounds	*pounds*	*pounds*	*pounds*
Normal soil	5,397			−512
Normal soil leached	5,040	−357	−48	−165
2 per cent NaCl	5,040			256
2 per cent NaCl leached	4,839	−201	−223	−140
2 per cent Na_2SO_4	5,090			288
2 per cent Na_2SO_4 leached	4,687	−403	−112	97
2 per cent Na_2CO_3	4,184			−752
2 per cent Na_2CO_3 leached	3,578	−606	−1066	35
1 per cent each NaCl, Na_2SO_4	4,334			29
1 per cent each NaCl, Na_2SO_4 leached	4,435	101	−199	112
1 per cent each NaCl Na_2CO_3	4,536			313
1 per cent each NaCl Na_2CO_3 leached	3,830	−706	−379	137
1 per cent each Na_2SO_4, Na_2CO_3	4,662			169
1 per cent each Na_2SO_4, Na_2CO_3 leached	4,133	−529	−438	−381
0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	4,536			327
0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3, leached	4,385	−151	−269	670
Corinne soil	4,738			335
Corinne soil leached	4,334	−404	−134	770
Richland acre	10,764			298
Richland acre leached	10,300	−464	−90	1142
Benson soil	2,066			54
Benson soil leached	1,210	−856	−507	418

cause a measurable gain of nitrogen in a soil and that the gain is in the same order as was found by the tumbler method.

The soil was shoveled direct from the field into the pots, hence the first accurate knowledge we have of the nitrogen content of each pot is that given in the first column. This was obtained by a careful analysis of the soil of each individual pot made at the close of the leaching period. The results given in the second column represent the loss due to leaching. They are based on the assumption that the two soils, leached and non-leached, contained soil of the same nitrogen content at the time they were put into the pots.

In column three is given the loss of nitrogen as calculated from the drain water. These two sets of results do not agree, nor should one expect them to for the following reasons:

1. Nitrogen fixation may have been greater in the leached than in the non-leached; hence, the leach water may carry nitrogen although the soil registers no loss in total nitrogen.
2. All of the nitrogen removed from the soil may not appear in the drain waters. The leaching soil filled with water has conditions ideal for denitrification, hence some of the nitrogen may disappear as gaseous nitrogen.

It is evident from the results that leaching has carried from the soil considerable nitrogen. This is greatest, as would be expected, where sodium carbonate is present.

The gain recorded in the second column where the sulfate and chloride were present should not be taken to indicate that no nitrogen was carried from the soil but that the gain due to fixation more than offset the loss due to leaching. Hence, the loss through leaching is the sum of the difference between the two soils plus the excess fixation in the leached soil.

The results given in the fourth column represent the gain or loss of nitrogen from these soils during two years. They are based on analysis of representative samples made in 1921 and again in 1923, and calculated to the dry basis.

It is certain from these results that some salts stimulate nitrogen fixation. The untreated soil registers a loss, whereas most of the alkali soils show a gain. The gain occurs in most cases more rapidly in the leached than in the non-leached soil, but even the alkali-containing soil shows measurable increases of nitrogen. The greatest gain is in the sulfate-containing soil. This is significant when it is recalled that it was from these soils that the azotobacter were recovered. Moreover it is clear that certain, as yet undetermined concentrations of various salts accelerate nitrogen fixation in soils.

CROP YIELDS FROM SOIL

The total dry weight and nitrogen in both the stalks and roots of the clover are given in table 19. Where no results are reported for a specific treatment it indicates that no crop grew on that soil. The results as reported are the averages for pots receiving the same treatment.

The leaching of the soil increased the total dry matter in the clover tops 38 per cent and in the roots 190 per cent. The total nitrogen is greatly increased, but the percentage of nitrogen in both roots and tops is decreased. The total dry matter is increased by both soil extract and manure over that in the leached soil; moreover, it is increased to the same extent by the soil extract as by the manure.

The soil containing 2 per cent of sodium chloride produced no crop. After being leached and treated with farmyard manure, the crop nearly equals that produced by the original soil. Here the manure is more effective than the soil extract, probably because of its ability to combine with and neutralize to a

TABLE 19

Weight of dry matter, total nitrogen, and percentage of nitrogen in clover roots and tops on various alkali soils

TREATMENT	ROOTS			TOPS		
	Weight dry matter	Total N	Total N	Weight dry matter	Total N	Total N
	mgm.	*per cent*	*mgm.*	*mgm.*	*per cent*	*mgm.*
Soil untreated	16.38	2.93	480	2.23	2.51	56
Soil leached	22.65	2.73	618	6.40	2.16	138
Soil leached + 15 T. manure	27.74	2.76	766	5.26	2.36	124
Soil leached + soil extract	28.26	2.80	791	4.91	2.13	105
Soil + 2 per cent NaCl, leached	13.99	3.10	434	2.86	2.46	70
Soil + 2 per cent NaCl, leached + 15 T. manure	15.25	3.23	493	3.11	2.67	83
Soil + 2 per cent NaCl, leached + soil extract	10.50	3.84	403	2.45	2.92	72
Soil + 2 per cent Na_2SO_4	0.24	3.31	8			
Soil + 2 per cent Na_2SO_4 leached	17.55	2.82	495	3.35	2.21	74
Soil + 2 per cent Na_2SO_4 + 15 T. manure	4.77	3.37	161	2.57	2.58	66
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure	19.47	3.48	330	1.73	2.61	45
Soil + 2 per cent Na_2SO_4 leached + soil extract	19.65	3.92	770	1.06	2.60	28
Soil + 2 per cent Na_2CO_3 leached	0.27	3.41	9	0.12	3.22	4
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure	1.69	4.56	76	0.74	2.51	19
Soil + 2 per cent Na_2CO_3 leached + soil extract	0.73	4.58	33	0.22	3.40	8
Soil + 1 per cent each Na_2SO_4, NaCl leached	9.02	3.71	334	0.92	2.88	27
Soil + 1 per cent each Na_2SO_4, NaCl leacehd + 15 T. manure	7.96	3.47	276	1.12	3.01	34
Soil + 1 per cent each Na_2SO_4, NaCl leached + soil extract	16.85	3.03	511	2.36	2.52	60
Soil + 1 per cent each Na_2CO_3, NaCl leached	0.01	5.35	1			
Soil + 1 per cent each Na_2CO_3, NaCl leached + 15 T. manure	6.63	2.59	172	4.42	2.46	109
Soil + 1 per cent each Na_2CO_3, NaCl leached + soil extract	0.61	4.70	29	0.40	2.80	11
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + 15 T. manure	3.50	4.10	144	0.42	3.06	13
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + soil extract	0.80	4.07	33	0.38	2.70	10
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4, NaCl leached	1.80	4.34	78	0.40	3.62	15
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4, NaCl leached + 15 T. manure	6.88	3.27	225	0.69	2.49	17
Soil + 0.66 per cent each Na_2CO_3, Na_2SO_4, NaCl leached + soil extract	3.35	4.01	134	0.45	2.01	9
Corinne alkali soil leached	6.13	2.85	175	1.25	1.81	23

TABLE 19—*Continued*

TREATMENT	ROOTS			TOPS		
	Weight dry matter	Total N	Total N	Weight dry matter	Total N	Total N
	mgm.	*per cent*	*mgm.*	*mgm.*	*per cent*	*mgm.*
Corinne alkali soil leached + 15 T. manure	7.14	2.80	200	0.36	2.11	8
Richland acre soil	0.59	2.89	171			
Richland acre soil + 15 T. manure	0.41	3.59	15			
Richland acre soil leached	0.07	4.38	3			
Richland acre soil leached + 15 T. manure	0.20	4.81	9			
Benson alkali soil leached	0.35	2.08	7			
Benson alkali soil leached + 15 T. manure	2.40	3.97	95			
Benson alkali soil leached + soil extract	0.26	2.85	7			

limited extent the soluble salts. The percentage of nitrogen in the plants grown on the alkali soil is considerably higher than that in the plants grown on the normal soil.

The sodium-sulfate-carrying soil produced only one weak plant, but when this same soil received 15 tons of manure it produced only one-fourth as much as the normal soil. The leaching of the soil brought it back to normal. Leaching and the addition of manure increase the crop to above normal. Here also there is an increase in the percentage of nitrogen in the plants due to the alkali.

The sodium-carbonate-treated soil produced no crop even after leaching, and it was meager even after manure had been applied to the soil.

The mixture of sodium chloride and sodium sulfate prevented all growth, and leaching was ineffective in bringing it back to normal. The manure and soil extract, however, made the soil productive. Similar results were obtained where the mixture of the three salts was used. The results clearly indicate carbonate to be most toxic and sulfate least—the same order as was found for the bacteria.

It is quite evident from these results that the natural alkali soil is much harder to reclaim than is the synthetic alkali soil. This is due to recognized physical and chemical differences in these soils, and these results indicate that there are also biological differences.

The conclusions which seem warranted from these results are:

1. Black alkali soil is very difficult to reclaim; in these experiments none of the black alkali soil was restored to producing normal yields. 2. Organic manures are essential in reclaiming alkali soil even where leaching is used. Furthermore some alkali-containing soils can be made to produce fair crops by the addition of manure. 3. Crops grown on alkali soil are higher in nitrogen than are those grown on non-alkali soil. 4. The dry matter in the clover tops was 4.2 times that in the roots. 5. There was nearly five times as much nitrogen in the tops as in the roots. This is considerably higher in the hay than is the value reported by others (7).

The average results for barley are given in table 20.

In every case except two, the leached soil produced more barley than did

TABLE 20

Weight of dry matter, total nitrogen, and percentage of nitrogen in straw and barley grain on the various alkali soils

TREATMENT	STRAW			GRAIN		
	Weight dry matter	Total N	Total N	Weight dry matter	Total N	Total N
	mgm.	*per cent*	*mgm.*	*mgm.*	*per cent*	*mgm.*
Untreated soil	7.1	1.09	77	2.4	2.13	51
Soil leached	7.1	0.92	65	3.1	2.18	68
Soil leached + 15 T. manure	10.7	1.35	144	3.3	2.44	81
Soil leached + soil extract	8.3	0.83	69	1.9	2.31	44
Soil + 2 per cent NaCl	6.4	2.16	138	0.4	3.92	16
Soil + 2 per cent NaCl leached	8.5	0.96	82	2.9	2.41	70
Soil + 2 per cent NaCl + 15 T. manure	6.6	1.86	123	1.0	3.28	33
Soil + 2 per cent NaCl leached + 15 T. manure	9.3	1.07	100	4.2	2.45	103
Soil + 2 per cent NaCl + soil extract	5.0	1.43	72	2.0	2.78	56
Soil + 2 per cent NaCl leached + soil extract	14.3	1.33	190	2.8	2.67	75
Soil + 2 per cent Na_2SO_4	5.9	1.20	71	2.8	2.16	61
Soil + 2 per cent Na_2SO_4 leached	15.1	2.20	332	2.8	3.12	87
Soil 2 per cent Na_2SO_4 + 15 T. manure	15.5	2.20	341	3.2	3.46	111
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure	17.8	1.68	299	2.4	2.76	66
Soil + 2 per cent Na_2SO_4 + soil extract	15.5	1.85	287	2.3	3.18	73
Soil + 2 per cent Na_2SO_4 leached + soil extract	17.5	2.10	368	2.6	2.85	74
Soil + 2 per cent Na_2CO_3 leached	2.4	1.33	32	0.2	3.56	7
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure	13.3	1.71	227	2.3	2.81	65
Soil + 2 per cent Na_2CO_3 leached + soil extract	6.1	1.75	107	2.1	2.01	42
Soil + 1 per cent each NaCl, Na_2SO_4	6.3	1.55	98	1.2	2.92	35
Soil + 1 per cent each NaCl, Na_2SO_4 leached	11.2	1.33	149	2.6	2.63	68
Soil + 1 per cent each NaCl, Na_2SO_4 leached + 15 T. manure	9.3	1.54	143	2.0	2.76	55
Soil + 1 per cent each NaCl, Na_2SO_4, leached + soil extract	7.4	0.90	67	2.8	2.17	61
Soil + 1 per cent each NaCl, Na_2CO_3	1.6	2.24	36	0.1	2.62	3
Soil + 1 per cent each NaCl, Na_2CO_3 leached	9.1	1.45	132	0.6	3.23	19
Soil + 1 per cent each NaCl, Na_2CO_3 leached + 15 T. manure	11.6	1.18	137	2.5	2.50	63
Soil + 1 per cent each NaCl, Na_2CO_3 leached + soil extract	11.27	0.93	105	3.6	2.23	80
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	3.2	3.17	101			
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	1.7	1.35	23	1.8	2.46	44
Soil + 1 per cent each Na_2SO_4, Na_2CO_4 leached 15 T. manure	12.2	1.27	154	3.4	2.45	83

TABLE 20—*Continued*

TREATMENT	STRAW			GRAIN		
	Weight dry matter	Total N	Total N	Weight dry matter	Total N	Total N
	mgm.	*per cent*	*mgm.*	*mgm.*	*per cent*	*mgm.*
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + soil extract	8.8	0.65	52	2.9	2.00	58
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3	10.4	1.45	151	2.4	2.43	58
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3, leached	13.1	1.90	249	3.3	2.52	83
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 + 15 T. manure	20.6	1.99	410	1.2	3.46	42
Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 + soil extract	15.8	1.91	302	3.9	2.60	101
Corinne soil			No crop			
Corinne soil + 15 T. manure	8.0	1.32	106	2.1	2.74	58
Corinne soil leached	13.5	1.15	155	2.90	2.46	71
Corinne soil leached + 15 T. manure	16.0	1.73	277	2.7	2.22	60
Corinne soil + soil extract	1.6	1.98	21			
Corinne soil leached + soil extract	15.4	2.90	447			
Richland acre soil	3.7	2.12	78	0.3	3.37	10
Richland acre soil + 15 T. manure	9.5	2.33	221	0.9	3.32	30
Richland acre soil leached	0.6	3.48	21			
Richland acre soil leached + 15 T. manure	9.5	2.48	236	0.6	2.92	18
Richland acre soil + soil extract	0.5	1.94	10	1.3	2.74	36
Richland acre soil leached + soil extract	7.7	1.38	106	3.2	2.65	85
Benson alkali soil			No crop			
Benson alkali soil + 15 T. manure			No crop			
Benson alkali soil leached	11.7	0.99	116	2.0	2.42	48
Benson alkali soil leached + 15 T. manure	20.9	1.80	376	0.9	2.58	23
Benson alkali soil + soil extract			No crop			
Benson alkali soil leached + soil extract	22.6	1.13	255	3.3	2.65	87

the unleached soil. There was also considerably more nitrogen removed in the grain from the leached than from the unleached soil. It is evident that the change produced in the bacterial activities of the soil by leaching is reflected in the crop yields. This increase is augmented by the manure, but no beneficial effect can be attributed to the inoculation. In reality, the results point to a depression caused by the soil extract, thus seeming to indicate that the soil extract has carried back into the soil the limiting factor of bacterial activity and growth.

Two per cent of sodium chloride retards but does not prevent plant growth. However, it does reduce the proportion of grain to straw and results in a straw and grain both of which are richer in nitrogen. Leaching increases the yield and reduces the percentage of nitrogen carried by the crop. Manure applied to the unleached soil has little value, but when applied to the leached soil is

TABLE 20

Weight of dry matter, total nitrogen, and percentage of nitrogen in straw and barley grain on the various alkali soils

TREATMENT	STRAW			GRAIN		
	Weight dry matter	Total N	Total N	Weight dry matter	Total N	Total N
	mgm.	*per cent*	*mgm.*	*mgm.*	*per cent*	*mgm.*
Untreated soil	7.1	1.09	77	2.4	2.13	51
Soil leached	7.1	0.92	65	3.1	2.18	68
Soil leached + 15 T. manure	10.7	1.35	144	3.3	2.44	81
Soil leached + soil extract	8.3	0.83	69	1.9	2.31	44
Soil + 2 per cent NaCl	6.4	2.16	138	0.4	3.92	16
Soil + 2 per cent NaCl leached	8.5	0.96	82	2.9	2.41	70
Soil + 2 per cent NaCl + 15 T. manure	6.6	1.86	123	1.0	3.28	33
Soil + 2 per cent NaCl leached + 15 T. manure	9.3	1.07	100	4.2	2.45	103
Soil + 2 per cent NaCl + soil extract	5.0	1.43	72	2.0	2.78	56
Soil + 2 per cent NaCl leached + soil extract	14.3	1.33	190	2.8	2.67	75
Soil + 2 per cent Na_2SO_4	5.9	1.20	71	2.8	2.16	61
Soil + 2 per cent Na_2SO_4 leached	15.1	2.20	332	2.8	3.12	87
Soil 2 per cent Na_2SO_4 + 15 T. manure	15.5	2.20	341	3.2	3.46	111
Soil + 2 per cent Na_2SO_4 leached + 15 T. manure	17.8	1.68	299	2.4	2.76	66
Soil + 2 per cent Na_2SO_4 + soil extract	15.5	1.85	287	2.3	3.18	73
Soil + 2 per cent Na_2SO_4 leached + soil extract	17.5	2.10	368	2.6	2.85	74
Soil + 2 per cent Na_2CO_3 leached	2.4	1.33	32	0.2	3.56	7
Soil + 2 per cent Na_2CO_3 leached + 15 T. manure	13.3	1.71	227	2.3	2.81	65
Soil + 2 per cent Na_2CO_3 leached + soil extract	6.1	1.75	107	2.1	2.01	42
Soil + 1 per cent each NaCl, Na_2SO_4	6.3	1.55	98	1.2	2.92	35
Soil + 1 per cent each NaCl, Na_2SO_4 leached	11.2	1.33	149	2.6	2.63	68
Soil + 1 per cent each NaCl, Na_2SO_4 leached + 15 T. manure	9.3	1.54	143	2.0	2.76	55
Soil + 1 per cent each NaCl, Na_2SO_4, leached + soil extract	7.4	0.90	67	2.8	2.17	61
Soil + 1 per cent each NaCl, Na_2CO_3	1.6	2.24	36	0.1	2.62	3
Soil + 1 per cent each NaCl, Na_2CO_3 leached	9.1	1.45	132	0.6	3.23	19
Soil + 1 per cent each NaCl, Na_2CO_3 leached + 15 T. manure	11.6	1.18	137	2.5	2.50	63
Soil + 1 per cent each NaCl, Na_2CO_3 leached + soil extract	11.27	0.93	105	3.6	2.23	80
Soil + 1 per cent each Na_2SO_4, Na_2CO_3	3.2	3.17	101			
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached	1.7	1.35	23	1.8	2.46	44
Soil + 1 per cent each Na_2SO_4, Na_2CO_4 leached 15 T. manure	12.2	1.27	154	3.4	2.45	83

TABLE 20—*Continued*

TREATMENT	STRAW			GRAIN		
	Weight dry matter	Total N	Total N	Weight dry matter	Total N	Total N
	mgm.	*per cent*	*mgm.*	*mgm.*	*per cent*	*mgm.*
Soil + 1 per cent each Na_2SO_4, Na_2CO_3 leached + soil extract	8.8	0.65	52	2.9	2.00	58
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Soil + 0.66 per cent each NaCl, Na_2SO_4, Na_2CO_3 + soil extract	15.8	1.91	302	3.9	2.60	101
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Corinne soil leached	13.5	1.15	155	2.90	2.46	71
Corinne soil leached + 15 T. manure	16.0	1.73	277	2.7	2.22	60
Corinne soil + soil extract	1.6	1.98	21			
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Richland acre soil	3.7	2.12	78	0.3	3.37	10
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Richland acre soil leached	0.6	3.48	21			
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Benson alkali soil leached	11.7	0.99	116	2.0	2.42	48
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Benson alkali soil + soil extract			No crop			
Benson alkali soil leached + soil extract	22.6	1.13	255	3.3	2.65	87

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Two per cent of sodium chloride retards but does not prevent plant growth. However, it does reduce the proportion of grain to straw and results in a straw and grain both of which are richer in nitrogen. Leaching increases the yield and reduces the percentage of nitrogen carried by the crop. Manure applied to the unleached soil has little value, but when applied to the leached soil is

very effective is increasing productivity. Here again very little influence could be attributed to the soil extract.

The sodium-sulfate-treated soil produced slightly less than the normal soil, but when leached and especially when treated with manure it was more productive than the untreated soil. Here again the soil extract is less effective than the manure.

The sodium-carbonate-treated soil produced no crop, and even after it had been leached, the yield was low until manure had been applied. The soil extract is beneficial but not to the same extent as is the manure. The percentage nitrogen in the crop is increased by sodium carbonate and sodium sulfate.

The toxicity of the mixture of the salts is less than that of the single salts. Hence, there appears to be an antagonistic action of the one salt toward the other.

The soil receiving the combination of the three salts was as productive as the untreated soil, and after being leached, and especially after treatment with manure or soil extract, produced a much greater crop than did the untreated.

It is evident from these results that the addition of the alkali to a soil and then the removal by leaching have increased its productivity and also modified the soil to produce a crop richer in nitrogen. Moreover, it is very evident from these results that farmyard manures must play a very prominent part in the reclaiming of alkali soil. This is brought out even more strikingly with the naturally occurring than with the artifically produced soil, for often the mere presence of manure is sufficient to determine whether there be a crop. This in some cases was true for both the leached and non-leached alkali soils. The Corinne soil in the absence of manure produced no crop; in the presence of manure the yield equalled that on the college farm soil. When this was leached and treated with manure or soil extract the crop yield was doubled. Similar results were obtained on the Richland acre soil. The Benson alkali which is heavily impregnated with black alkali became productive only after leaching. After leaching, both the soil extract and manure is highly efficient in increasing productivity.

Conclusions drawn from these results can be accepted as only tentative, indicating the plan which should be followed in future work in both pot and field experiments. They are published at this time, as the nature of the work has been such that further cropping on these soils is impracticable. The large quantities of soil removed in the sampling has left an insufficient amount for normal plant growth. Although it is realized that the results in many cases are inconclusive and bring out strikingly the need of more refined bacteriological methods to measure the biological differences of various soils, yet they conclusively prove that in the reclaiming of alkali soil there is a biological as well as a chemical and physical problem and that careful biological studies of soil alkali problems will yield results just as valuable as are now being obtained by recent chemical investigations.

CONCLUSIONS

The soils used in this work were three natural alkali soils: one in which chlorides predominated, a second in which the sulfates predominated, and a third which was heavily impregnated with sodium carbonate. A productive calcareous silt loam, which was made into an alkali soil by various treatments with sodium chloride, sulfate, and carbonate, was also used.

These were leached in 2-gallon jars to remove as much as practicable of the soil alkali. The soils were then sampled and manured or inoculated and cropped first to clover and afterwards to barley.

The leaching of the normal soil increased the bacterial activities and the productiveness.

Two per cent of sodium chloride decreased the bacterial numbers 11 per cent. Leaching caused an increase of 38 per cent over the normal soil. The results for the soil receiving 2 per cent of sodium sulfate were within the experimental error of those in the untreated soil.

Two per cent sodium carbonate reduced the numbers 24 per cent. Leaching increased them 830 per cent. That is, in all cases the leaching of the alkali and non-alkali soils increased the number of microorganisms.

Two per cent of sodium chloride reduced ammonification to 10 per cent of normal; sodium carbonate to 41 per cent of normal; and sodium sulfate to 52 per cent of normal. Leaching in many cases increases ammonification to above that occurring in the normal soil. Soil extract and manure were very effective in restoring ammonification in alkali soils.

Sodium carbonate is more toxic when measured in terms of nitrification than is either the chloride or the sulfate. The carbonate reduced nitrification to 7 per cent normal, the chloride to 12 per cent normal, and the sulfate to 47 per cent normal. Nitrification was very low even after leaching but was increased by both soil extract and manure, thus showing that the soil needs inoculation after the removal of the alkali.

Inconclusive results were obtained in nitrogen fixation by the tumbler method but very uniform results were obtained where the soil was seeded into Ashby media. Here alkalies retarded the fixation of nitrogen and in every case there was an increase caused by leaching.

Test of the soil at the beginning and end of the experiment showed that in most cases measurable quantities of nitrogen had been fixed and some of the alkalies, especially the sulfate, increased the rate of gain of nitrogen in the soil. This was especially true in the case of a natural alkali soil very high in sulfates.

The results indicate that the nitrogen fixing organisms are more resistant to soluble salts than other benefical microorganisms.

The leaching of the soil increased the crop yield, and some of the alkali very markedly increased the nitrogen content of the plants.

It is evident from these results that organic manures are essential for the restoration of alkali soils to a high state of productivity. Benefits will often

result from the proper inoculating of alkali soils which are being reclaimed by leaching.

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THE NORMAL MOISTURE CAPACITY OF SOILS

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When water is applied to the surface of a more or less dry soil, it flows down through the interstices of the soil mass wetting the soil grains over which it passes. If the soil be *uniform in texture and structure and the quantity of water just sufficient to wet it to the full depth of uniformity,* or to a change in the soil character, *the amount of water retained on any of the soil grains throughout the entire depth will be approximately the same.*

If the quantity of water be insufficient to wet the full depth of uniform soil, the moisture content will be approximately uniform from the surface to within a few inches of the bottom of the wetted soil, where a rapid decrease occurs, the amount tapering down sharply to the dry soil. The depth to which the moisture penetrates is readily discernible, the change or break from wet to dry soil being very abrupt, and usually marked by a distinct change in color.

The flow of water downward through the soil mass is the result of two forces, gravity and an inverted "capillary movement" or film force. As the water moves down through the soil, a part is absorbed and held by the colloidal material present and an additional amount is held as thin films surrounding the soil grains with thicker waist-like accumulations where the grains touch each other. The downward pull of the "capillary" or film forces, augmented by the pull of gravity, reduces these films to a minimum thickness, and the curve of the water-air surfaces is sharp at points where the soil grains are in contact. When all the water is used in wetting the soil to this degree, further movement through the soil of water in the liquid phase is exceedingly limited and the moisture condition becomes essentially static.

LITERATURE

There is a voluminous literature dealing with soil moisture in general, usually with the "capillary rise" and drainage phenomena, but with relatively little bearing directly on downward percolation and the resulting distribution of the soil moisture.

Rotmistrov (5) has discussed this distribution and given field data showing relatively uniform moisture content within soil horizons that apparently have uniform characteristics.

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He gives no information on the texture or structure of these soil horizons, however, and the relation between the moisture holding capacity and the observed moisture can not be checked.

Burr (2, 3) has dealt with the problem in several papers, nearly all based on field observation and study where, however, the final moisture distribution is complicated by the presence of growing vegetation.

Alway and McDole (1) have discussed the downward movement of moisture and the resulting distribution in soils differing in textures from sands to silt loams. Short tubes (14.22 inches) were used and the distribution is reported in three and four sections after a period of five days or less. They concluded that "at the end of five days equilibrium had been practically attained in the fine-textured soils, but in the coarser one this was far from being the case. The coarser the soil the more slowly was equilibrium reached."

Scofield (6) has added to the data and discussion, as have many other investigators who have touched upon the problem incidental to other studies.

Israelsen and West (4) have studied the problem in the field, using large applications of water, with results that generally agree with the findings reported in this paper. They state that, "ten days after the heavy irrigations were applied by the authors each of the plots held the same amount of available water, namely 1½ inches per foot in the upper 6 feet." In their conclusions, however, they state: "In the opinion of the authors, the downward movement of the water must continue until equilibrium is established with the water table. Moisture determinations that were made throughout the summer after the 10-day tests showed a continuous but very slow downward movement of water, thus confirming this opinion."

Widtsoe and McLaughlin (9) in their studies on the Greenville soil have recognized a relatively static soil moisture distribution for this soil at 12.68 per cent moisture, which they termed the "point of lento-capillarity" and which is well above the hygroscopic coefficient of 4.33 per cent. They did not, however, associate this with what they termed the "optimum capillary capacity or field water capacity" of this soil, which was placed at 18 per cent or about 5.3 per cent higher than the point of lento-capillarity. In the experiments conducted in our laboratories, there is strong evidence that at the "normal moisture capacity" which would correspond to Widtsoe's "field water capacity," the soil moisture condition is practically static.

Shantz (7) in a recent contribution has ably set forth a theory and conclusion essentially identical with that given herewith, but without any supporting data, although in earlier publications he had indirectly given much supporting evidence.

Veihmeyer (8), in the results of exhaustive field investigations extending over several seasons, has given ample evidence of the soundness of the theories when applied to field practice in irrigated regions.

The problem has been under investigation in our laboratories for over ten years, and from the data thus accumulated the following evidence is submitted.[2]

EXPERIMENTAL WORK

The soil

Various soils ranging in texture from medium sands to clay loams were used during the experiment. The movement of water through the heavier-textured soils was so slow that the results were unsatisfactory and inconclusive and the more extended experiments were conducted with medium-textured soils. All the results herein reported were obtained by using a Yolo fine sandy loam soil

[2] Acknowledgment is due to B. F. Monroe, to E. V. Winterer, and to the many graduate students who have contributed to the work.

containing approximately 8.5 per cent clay, 11.5 per cent silt, and 70 per cent fine and very fine sand. As the experiments were continued over a period of several years, succeeding quantities of soil varied slightly in mechanical composition. The results given in tables 1 and 2 were from soils having a moisture equivalent just above 14 per cent, and those in tables 4 and 5 from a soil having a moisture equivalent of 15.88 per cent.

Methods

Brass tubes 4 inches in diameter and of 18-inch and 36-inch lengths were used for most of the work, while galvanized iron tubes 6 and 8 inches in diameter and from 4 to 8 feet long were used for a few tests.

The brass tubes were filled on the propeller type of compactor, giving a very uniform compaction of the soil throughout the full length of the container. The larger tubes were filled by carefully pouring in the soil, jarring to gain compaction. The distribution within the larger tubes was much less satisfactory, considerable stratification of the soil occurring in some cases.

Water was applied at the surface in quantity sufficient to give the desired depth of irrigation, a depth or head of 1 to 1½ inches usually being maintained until all the water had been applied. Drip and sprinkling were used as means of application in certain cases when it was desired to eliminate the effect of "head." As soon as the water had disappeared from the surface the tubes were closed with a closely fitting, but not air-tight, cover in order to retard or prevent evaporation.

When a specified period of time had elapsed, the soils were sampled by removing, with a specially devised sampling tool, all the soil to the desired depth. In most cases the soils were sampled by 1-inch sections. The soil was quickly mixed, sub-sampled, and weighed into dishes and dried for from two to five days at 100°C. All results are reported at percentages of moisture based on the oven-dry weight of the soil.

EXPERIMENTAL DATA

Experimental results are given from only a few of the numerous tests made, selected to cover the several points discussed. Table 1 and figure 1 show the moisture distribution 5 days after irrigation of 18-inch tubes when 2, 2½, 3 and 3½ inches of water were applied. The soils were sampled by 1-inch sections and the results are the mean of duplicate tubes.

Although the depth of penetration varied in direct relation to the amount of moisture applied and the quantity above the taper was rather close in all the tubes, it was evident that downward movement had not ceased and that a longer period of time was needed before equilibrium would be established.

Table 2 and figure 2 show results where the amount of water applied was the same, but the time varied. Five tubes were used, irrigated with 2½ inches of water, and allowed to stand 5, 7, 11, 21 and 28 days, protected from evapora-

tion as indicated above. The total penetration varied from 11 to 14 inches, with tapers of from four to five inches. All the tubes show a decrease in the amount of moisture from the surface downward, the slope becoming steeper as the time increased.

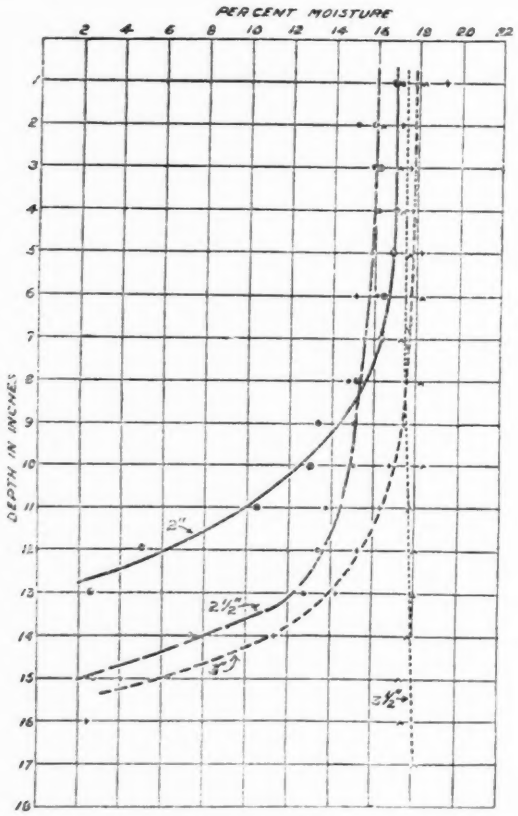

FIG. 1. EFFECT OF INCREASED AMOUNTS OF WATER. SAMPLED FIVE DAYS AFTER APPLICATION

——— = 2.0 inch depth of water applied; — — — = 2.5 inch depth of water applied; - - - - = 3.0 inch depth of water applied; ---------- = 3.5 inch depth of water applied.

Because of the shallow depths of the soil, the uniformity of distribution in the 21- and 28-day tubes was considered as not sufficiently conclusive and for this reason other tests using longer tubes were undertaken. Brass tubes 4 inches in diameter and 36 inches long were used and irrigations giving 6, 7, and 8 inches of water applied. One set of tubes was sampled at the end of 24 days,

TABLE 1

Effect on moisture distribution of increased amounts of water

DEPTH OF SOIL	DEPTH OF WATER APPLIED			
	2.0 inches	2.5 inches	3.0 inches	3.5 inches
inches	*per cent**	*per cent*	*per cent*	*per cent*
1	16.81	17.00	19.19	18.13
2	15.84	14.94	17.19	16.05
3	16.00	15.70	17.60	17.02
4	16.90	16.00	17.80	17.20
5	16.86	15.70	18.11	17.60
6	16.66	16.03	15.01	18.12
7	16.16	15.41	17.85	17.43
8	15.10	14.78	17.75	18.13
9	13.36	15.00	17.72	19.22
10	13.00	15.05	16.79	18.49
11	10.37	13.85	16.30	17.82
12	5.25	13.33	15.11	18.02
13	2.44	12.91	14.15	18.02
14	.....	7.32	11.30	17.85
15	.....	2.45	3.96	17.22
16	.....	.....	2.30	17.53
17	.....	.....	.....	18.09

* Based on oven-dry weight of soil.

TABLE 2

Effect of time on moisture distribution

DEPTH OF SOIL	TIME ELAPSED BEFORE SAMPLING				
	5 days	7 days	11 days	21 days	28 days
inches	*per cent**	*per cent*	*per cent*	*per cent*	*per cent*
1	21.25	18.59	19.02	15.95	15.04
2	18.45	17.10	16.38	13.72	14.78
3	18.27	16.71	15.80	14.25	14.73
4	17.81	17.37	16.10	14.15	14.04
5	18.33	17.16	16.29	14.07	14.53
6	17.78	16.14	15.39	14.34	14.24
7	17.87	16.34	15.67	14.54	14.44
8	16.70	15.75	14.72	14.04	14.14
9	16.41	14.58	14.07	13.71	13.58
10	14.87	13.48	13.34	13.00	13.08
11	13.48	12.72	12.18	11.94	12.66
12	11.45	11.79	3.65	9.97	12.07
13	3.72	4.60	.....	7.93	10.04
14	2.90	.....	.....	2.92	4.65
15	2.59	.....	3.17	2.21	3.68

* Based on oven-dry weight of soil.

and a second set after 54 days. Table 3 gives the moisture content by inches, and figure 3 shows the moisture distribution at the end of 54 days.

It is evident that the moisture had not reached a uniform distribution or a state of equilibrium in any of the tubes, although that condition is approximated after 54 days in the tubes receiving 6 and 7 inches of water. The water had reached the bottom of the tubes which received the 7- and 8-inch irrigations,

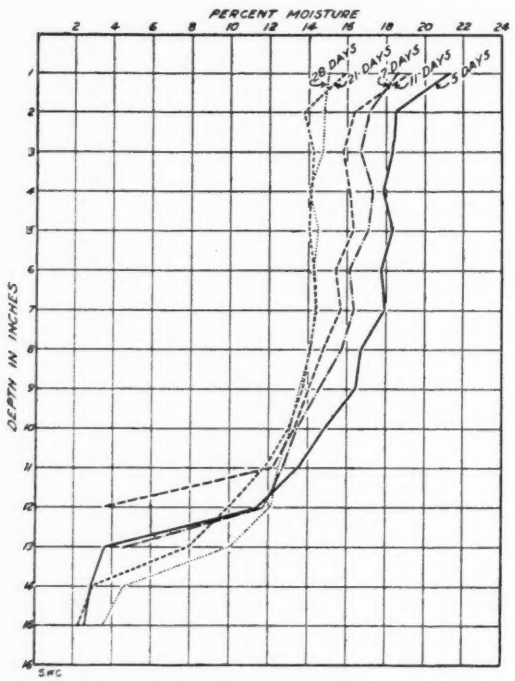

FIG. 2. EFFECT OF TIME ON MOISTURE DISTRIBUTION WHEN 2.5 INCHES OF WATER AS APPLIED

——— = 5 days; —·—·— = 7 days; — — — = 11 days; ---------- = 21 days; ..... = 28 days.

making it evident that not over 6 inches of water could be held within the 36-inch soil column without wetting the soil to its entire depth.

The distribution as affected by a still more prolonged period is shown in table 4 and figure 4, which give the results obtained from tubes that received 6 inches of irrigation water and stood for 24, 54, 89, and 123 days.

The soil moisture had not ceased its downward flow in 89 days, but by 123 days the distribution closely approaches uniformity to a depth of 24 inches where the taper appears to begin. The average content of moisture (table 5)

from the surface to the twenty-fifth inch (excluding the eleventh inch) is 16.79 ± 0.365, expressed as percentage of the dry weight. There appears to

TABLE 3

Distribution of water—effect of time and quantity

DEPTH	SIX INCHES		SEVEN INCHES		EIGHT INCHES	
	24 days	54 days	24 days	54 days	24 days	54 days
inches	*per cent**	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1	21.70	19.04	20.50	21.10	23.53	22.70
2	19.52	18.15	19.82	19.33	21.38	20.50
3	19.73	18.38	19.64	18.96	20.54	20.32
4	20.84	16.48	20.02	19.05	20.85	20.32
5	19.61	18.05	19.48	18.96	21.03	20.50
6	19.52	17.53	19.84	18.95	21.15	20.70
7	20.53	18.28	20.43	19.41	21.32	20.61
8	22.53	18.88	20.01	19.48	21.10	21.45
9	.....	18.50	19.82	19.39	21.72	21.15
10	20.04	18.56	20.70	19.63	22.20	21.15
11	20.67	18.93	20.68	19.23	.....	21.47
12	20.79	18.41	20.70	19.57	21.63	21.50
13	20.64	18.15	21.28	19.55	21.30	21.82
14	20.75	18.75	21.38	19.60	22.38	22.25
15	20.45	16.95	21.10	19.63	22.42	21.88
16	20.28	18.70	21.62	19.42	21.75	22.10
17	20.30	17.85	21.22	19.63	22.27	22.33
18	19.96	18.52	16.50	19.41	22.58	22.47
19	19.05	18.52	21.10	19.83	22.45	22.70
20	17.94	18.25	21.11	19.15	22.23	21.28
21	18.65	17.42	20.80	19.65	22.40	21.99
22	18.32	17.49	20.28	19.21	22.23	22.02
23	18.35	17.28	20.18	19.13	22.30	22.71
24	17.42	16.80	14.35	18.95	21.70	22.20
25	16.74	16.40	19.42	18.83	20.72	21.58
26	15.90	15.63	18.90	18.52	22.22	21.42
27	14.35	15.62	19.05	18.61	20.89	18.24
28	12.46	15.01	18.53	18.49	20.89	21.98
29	5.91	14.21	17.68	18.31	20.18	22.28
30	3.33	13.68	16.40	14.20	19.69	21.65
31	.....	9.25	15.95	13.75	19.92	21.65
32	.....	5.23	14.51	13.74	19.86	22.10
33	.....	4.43	10.20	13.48	20.42	22.81
34	.....	3.72	4.32	13.60	20.08	22.42
35	.....	.....	.....	16.90	17.65	21.90
36	.....	.....	.....	.....	.....	.....

*Based on oven-dry weight of soil.

be a slightly larger amount of moisture between the twelfth and seventeenth inches, but the largest variation, as shown in table 5, is only +0.53 as

compared to the average, or about 3 per cent of the average amount of moisture present.

That there was little or no evaporation loss and that the differences of distribution are due to moisture movements within the soil mass was shown by measurements of the areas within large scale graphs showing the distribution in the 24-, 54-, 89-, and 123-day tubes, where every point was located, and there

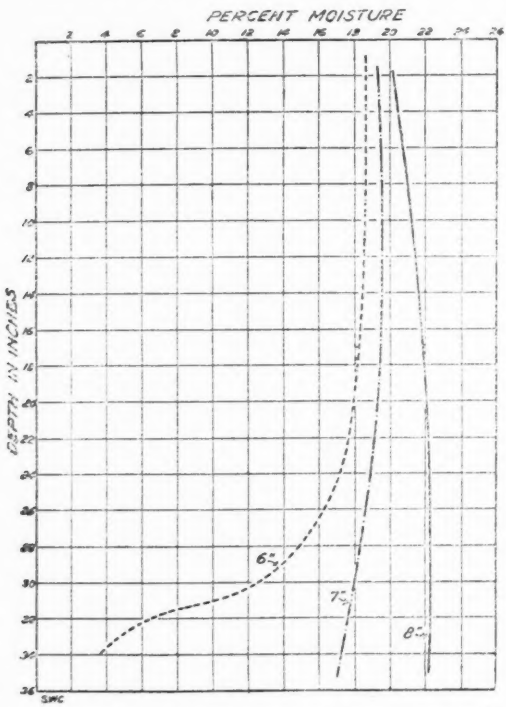

FIG. 3. EFFECT OF QUANTITY ON DISTRIBUTION OF WATER, SAMPLED 54 DAYS AFTER APPLICATION

———— = 8-inch application; —·—·— = 7-inch application; ---------- = 6-inch application.

was no "smoothing" of the curve as in *A*, *B*, *C*, and *D* in figure 4. The area within *A* (24-day) was taken as 100, *B* (54-day) was found to be 98.5, *C* (89-day) to be 99.9, and *D* (123-day) to be 99.5. As these figures were obtained from different tubes of soil after standing for long periods of time the agreement is surprisingly close.

It is believed that the moisture at the end of 123 days had approximately reached equilibrium insofar as flow in the liquid phase is concerned, and that

any further movement would have to take place in the vapor phase. It is possible that a very slow downward flow might continue for some time, slightly

TABLE 4

Distribution of water in tubes receiving a 6-inch irrigation, after prolonged periods of adjustment

DEPTH	TIME			
	24 days	54 days	89 days	123 days
inches	*per cent**	*per cent*	*per cent*	*per cent*
1	21.70	19.04	17.64	17.32
2	19.52	18.15	16.95	16.72
3	19.73	18.38	17.02	16.11
4	20.84	16.48	16.93	16.67
5	19.61	18.05	17.25	16.72
6	19.52	17.53	17.25	16.45
7	20.53	18.28	17.47	17.26
8	22.53	18.88	17.44	17.32
9	.....	18.50	17.41	16.60
10	20.04	18.56	17.57	16.82
11	20.67	18.93	17.86	15.24
12	20.79	18.41	16.82	17.16
13	20.64	18.15	18.14	17.00
14	20.75	18.75	18.05	17.13
15	20.45	16.95	17.78	16.84
16	20.28	18.70	18.24	17.32
17	20.30	17.85	17.45	17.23
18	19.96	18.52	17.58	16.83
19	19.05	18.52	17.46	16.69
20	17.94	18.25	16.92	16.39
21	18.65	17.42	17.09	16.54
22	18.32	17.49	17.02	16.68
23	18.35	17.28	16.65	16.32
24	17.42	16.80	16.57	16.16
25	16.74	16.40	16.00	15.72
26	15.90	15.63	15.90	15.79
27	14.35	15.62	15.55	15.62
28	12.46	15.01	15.23	15.17
29	5.91	14.21	14.83	14.88
30	3.33	13.68	14.34	14.42
31	.....	9.25	13.53	13.95
32	.....	5.23	12.64	13.62
33	.....	4.43	11.09	12.73
34	.....	3.72	8.12	11.07
35	.....	.....	6.06	8.29
36	.....	.....	3.92	6.62

* Based on oven-dry weight of soil.

reducing the moisture in the upper portion and increasing the depth of penetration. Table 4 shows that at the depth of 27 inches, the moisture content

has remained approximately constant after the fifty-fourth day, at a content of 15.62, 15.55 and 15.62 per cent. This evidently is a "critical" moisture point and may represent the content at equilibrium toward which the moisture is working.

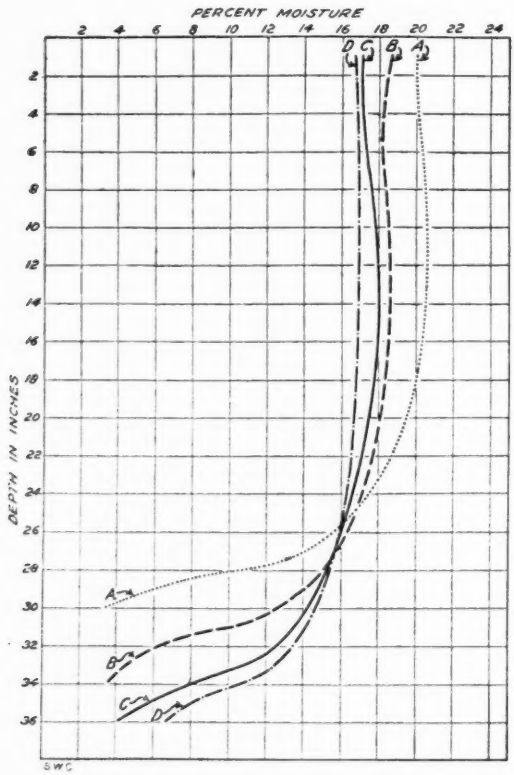

FIG. 4. DISTRIBUTION OF WATER IN TUBES RECEIVING A 6-INCH IRRIGATION, AFTER PROLONGED PERIODS OF ADJUSTMENT

..... A = Distribution after 24 days; — — — B = Distribution after 54 days; ——— C = Distribution after 89 days; —·—·— D = Distribution after 123 days.

The average moisture equivalent of the soils used in this test was found to be 15.88 ± 0.34, the variations of the individual tests being shown in table 6.

The close agreement of this moisture equivalent of 15.88 with the content of water at the twenty-seventh inch of 15.62 suggests that the normal moisture content of this soil when at equilibrium with the film and gravity forces is almost identical with the moisture equivalent. The average content at the end of 123 days, 16.79 per cent, is only 1.057 times the moisture equivalent; or

TABLE 5

Moisture content of 123-day tube above taper or to a depth of 24 inches, with averages and variations

DEPTH	PER CENT	VARIATION FROM AVERAGE
1	17.32	+0.53
2	16.72	−0.07
3	16.11	−0.68
4	16.67	−0.12
5	16.72	−0.07
6	16.45	−0.34
7	17.26	+0.47
8	17.32	+0.53
9	16.60	−0.19
10	16.82	+0.03
11	(15.24*)	.....
12	17.16	+0.37
13	17.00	+0.21
14	17.13	+0.34
15	16.84	+0.05
16	17.32	+0.53
17	17.23	+0.44
18	16.83	+0.04
19	16.69	−0.10
20	16.39	−0.40
21	16.54	−0.25
22	16.68	−0.11
23	16.32	−0.47
24	16.16	−0.63
Average.....	16.79	±0.365
Coefficient of Variation.....		2.15

* Not included in average.

TABLE 6

Moisture equivalents on soil from tubes

	VARIATION
	15.78 −0.10
	15.65 −0.23
	16.20 +0.32
	15.28 −0.60
	16.27 +0.39
	15.80 −0.08
	16.21 +0.33
Average =	15.88 ±0.34
Coefficient of Variation = 2.14	

expressing it the opposite way, the moisture equivalent is 94.6 per cent of the average moisture content. The soil as packed in the tubes had a volume weight of 1.315 and a pore space of 50.4 per cent. At the average moisture content at the end of 123 days, 43.8 per cent of the pore space was occupied by moisture, whereas at the moisture equivalent point, 41.4 per cent of the pores are filled with water. The downward movement of water under the combined forces of gravity and film pressures is very rapid, as shown in figure 1 and also in figures 2 and 4 in which time is a factor. Although the distribution at the end of five days is surprisingly uniform, the final distribution condition requires a long period of adjustment.

DISCUSSION OF RESULTS

The experimental evidence indicates that when water is added to a body of uniform soil and allowed to percolate downward through the soil mass, a condition of distribution will be reached at which the moisture content at any depth will be approximately the same, except for a region of very rapid decrease in moisture present in the lowest five or six inches of wetted soil. This zone of rapid decrease has been designated the "taper."

The distribution above the taper, when graphically represented, closely approaches a straight line provided the sampling of the soil is delayed for a sufficient time to allow this condition of equilibrium to be reached. If the amount of water added be just sufficient to wet the soil down to a change in texture, the moisture distribution throughout the full depth will be uniform. If any additional water be added, the amount held at any level will be increased, but with larger amounts in the lower depths, until at the maximum moisture capacity the curve or gradient of moisture content will approach that of the upper section of a "capillary potential" gradient.

Plotting the distribution obtained by adding increasing amounts of water gives a "pendulum" swing to the curves. In figure 1, curves 2, 2½, and 3 show the "deficiency" curve with a slope to the left. A theoretical distribution of exactly the right amount of added water would be straight lines showing uniform distribution. Curve 3½ shows a slope to the right occurring when a slight excess of water was added. In figure 3 the curves representing distribution after application of 6, 7 and 8 inches of water show the same type of swing, the 6-inch curve having a "deficiency" slope to the left and the 8-inch curve an "excess" slope to the right. In figure 4 all the graphs show "deficiency" curves to the left.

The term "Normal Moisture Capacity" is proposed as an expression indicating the moisture content of the uniform distribution approximated in curve *D*, figure 4, showing the distribution after 123 days. This amount approaches closely the condition described by Widtsoe (9) as the "optimum Capillary Water Capacity or Field Water Capacity." However, the author's conception of the condition of this water is that it is essentially static, that it will not move

upwards, downwards, or laterally, a condition which Widtsoe recognized and designated as the "Lento-Capillary Point," but which he placed materially lower in amount of water than his "Field Water Capacity."

This water is held in the soil by two phenomena. A portion is taken up by the colloidal material present as absorbed or adsorbed water. This portion is very firmly held and is not free to move under any of the forces present in the soil. The second portion is the water film over the surface of the soil particles (and colloid coating) with waist-like accumulations where the particles are in contact. The force of gravity and the capillary forces directed downward will move the film water down until the angles of the surfaces at the points of contact are acute and sub-catenoid, giving them a high film pressure. The remaining film water can not then move in any direction in the soil, and would correspond to the condition of lento-capillarity.

If the surface were dried out, this moisture could not move upward to any measurable extent. The upper few inches might dry by direct evaporation from the surface and soil pores, and develop a "taper" comparable to that at the lower extremity of the wetted zone. The depth of this taper would depend on the texture and structure of the soil, the size of the soil particles, and the effective size of the pores of the soil. Upward movement to replace the moisture lost by such surface evaporation is exceedingly slight and the depth so affected is very limited; as the thinness of the films and the sharp angle of the contact surfaces are the result of the original "capillary" forces plus gravity, upward capillary or film movement against gravity will be negligible or non-existent. A slow movement of moisture may occur in the vapor phase by normal vapor pressure phenomena, which would cause a movement toward any region of drier soil, thus tending to equalize the moisture content throughout the soil column. A definite loss may occur through the movement of air in the pores of the soil, the daily out-movement as the soil is warmed and the air expands, and the corresponding in-movement at night when the soil cools producing a "ventilation" and a removal of water vapor that will slowly reduce the soil moisture. The amount thus lost is small and the rate of such loss decidedly slow. At the Normal Moisture Capacity, the soil moisture is considered to be in a static condition or at least in such a state that movement of the liquid phase in any direction is exceedingly limited and negligible.

WATER OF ADHESION

The term "Water of Adhesion" is proposed to designate the water held in the soils under these conditions, defined essentially as follows:

> Water of Adhesion is that moisture in excess of the hygroscopic water, held in the soil by colloidal adsorption and as films surrounding the soil grains, not free to move under the normal influences of film forces.

The so-called "forms" of soil moisture would then become hygroscopic water, adhesion water, capillary water, and gravitational water.

Hygroscopic water is variously defined as the amount of water present in an air-dry soil, while the hygroscopic coefficient is defined by Hilgard as the amount of water a dry soil will absorb from a saturated atmosphere at a uniform temperature of 15°C.

Capillary water is usually designated as that water held on or between the soil grains by the adhesion between the soil and water and by surface tension forces and that is free to move under the influence of film forces.

Gravitational water is obvious—the excess water that can or will drain from a soil by gravity. It therefore should not properly enter into consideration as soil moisture but rather as a source of soil moisture.

Adhesion water would lie between the hygroscopic and the capillary water, covering the amount held between the hygroscopic coefficient and the point of lento-capillarity.

APPLICATION OF RESULTS

Irrigation. Applying water to the surface of a deep uniform soil would ultimately result in a moisture distribution at the Normal Moisture Capacity. Any additional water would serve to increase the depth of penetration, but not the amount held at any given depth, and if the amount added were sufficient to wet the soil beyond the reach of the roots, the excess moisture penetrating the lower layers would be lost to the plant. "Storing up" of water in a deep soil by winter irrigation or by the application of excessive amounts early in the season when water is abundant is impossible unless there is an impervious layer that will prevent further downward movement and result in a perched water table and a zone of saturation.

Mulches. When the soil is wetted to its Normal Moisture Capacity by rain or by irrigation, and this moisture is not free to move under the influence of film forces, as indicated in these experiments, then the "capillary rise" of this water is impossible and continued loss of moisture from the surface can not take place. The surface few inches will dry out to a depth about that of the usual mulch in arid regions. Beyond this drying can proceed only through vapor movements. A mulch can not prevent moisture movements which do not occur! Under such conditions therefore a mulch is of little or no effect.

Greenhouse practice. In experimental work in plant culture, soils are often moistened to the "optimum moisture content" before being placed in the pots, the seeds or plants are then planted and the system sealed. The loss of water by evaporation or transpiration, as determined by decreased weight, is replaced by adding the equivalent amount to the surface of the soil. Optimum Moisture Capacity is well below the normal Moisture Capacity. Water added to the surface will not be distributed uniformly through the soil mass until it reaches a uniform conditon of "optimum," but will remain at the "normal" moisture content, wetting a much shallower depth. The result is a wetted zone near the surface in which the roots can develop and grow, with

a lower zone dried down to the wilting point and more or less devoid of roots. This inequality in moisture distribution may vitiate the results of otherwise carefully controlled experiments.

CONCLUSIONS

A soil has a Normal Moisture Capacity which represents the minimum amount of water that is retained by absorption and film forces when the water is free to move downward through a mass of uniform soil.

The Normal Moisture Capacity is, for medium-textured soils, approximately the same as the moisture equivalent.

At the Normal Moisture Capacity the moisture is readily available for plants, but is not free to move under the normal film forces existing in the soil—it is essentially static.

In this condition, mulches are of little or no effect in conserving soil moisture, as upward movement to supply evaporation does not occur.

In deep uniform soil any water added by rain or irrigation penetrates the soil rapidly and soon approaches the Normal Moisture Capacity state of distribution.

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THE HYDROMETER AS A NEW AND RAPID METHOD FOR DETERMINING THE COLLOIDAL CONTENT OF SOILS

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Unquestionably one of the greatest needs in soil study is a very rapid and simple method for determining the colloidal material in soils, for the colloidal material seems now to constitute the seat of all the reactivities in soils. Such reactivities or relationships as base exchange, adsorbability and retainability of plant-food constituents, reactivity toward chemical reagents, solubility, heat of wetting, wilting coefficient, availability of water, evaporation of water, capillary movement of water, water holding capacity, rate of percolation, etc., are all controlled or influenced very largely by the colloidal content of a soil. In the last two years two methods which appear to come closest to giving a true estimation of the colloidal material in soils have been proposed. These two methods are the heat of wetting (1, 2) and the adsorption (4) methods. The chief drawback in both of these methods, however is that a portion of the colloids has to be extracted from the soil before the colloidal content can be determined, and this extraction process takes much time—in some soils, and where only small amounts are available it takes several days to extract enough colloids for an accurate adsorption or heat of wetting determination. Of the two methods, the heat of wetting is the quickest and simplest, but the adsorption method may take almost a week. It was once hoped that both the heat of wetting and the adsorption methods might be very rapid for estimating the colloidal content of soils, either the adsorption or the heat of wetting of the colloids being used as a factor, but it has been found that the colloids from different soils vary so greatly both in their adsorption and heat of wetting, that no factor can be used for all soils.

At this laboratory, therefore, attention and efforts have been directed elsewhere, with the hope of discovering a method or a factor which could be used for estimating very quickly and accurately the colloidal content of soils. This requirement seems to be happily furnished by the hydrometer method.

[1] At the request of the author this paper replaces that submitted July 23, 1926, "The Hydrometer as a New and Rapid Method for Estimating the Colloidal Material in Soils," a preliminary report of the investigations herein presented in final form. It is also given the position scheduled for "The Hydrometer as a New Method for the Mechanical Analysis of Soils" received for publication July 6, 1926, which thus relinquishes its priority rights as of July 6 and assumes those of July 23, 1926.

The employment of this method in connection with soil suspensions has revealed two remarkable facts; first, that the hydrometer can be used in measuring the rate of settling of soil particles (3) from which a distribution curve of the soil particles of various sizes might be worked out mathematically, and second, that it can estimate the colloidal contents of soils quite accurately and very rapidly.

It has been found that if a certain quantity of soil is dispersed in a definite amount of water, the percentage of the material that stays in suspension for 15 minutes, based on the original sample taken, is equal to the percentage of the colloids indicated by the heat of wetting method. This relationship is surprisingly close, with very few exceptions, and holds true for all types and horizons of soils and even when the quantity of soil is varied. The exceptions are mainly in soils that are unusually rich in organic matter especially in matter not thoroughly decomposed. Out of about 40 soils examined in the present investigation, however, which include a very good representation of all the different types and horizons, only 3 gave somewhat wide disagreement and this did not amount to more than 10 per cent.

On first consideration such a relationship as appears to exist between the percentage of colloidal material as determined by the heat of wetting method and the percentage of the material staying in suspension at the end of 15 minutes, might seem to be almost incredible or accidental. On further and deeper consideration, however, this relationship appears to be reasonable and logical. For instance, if different soils contain various amounts of fine or colloidal material, should we not expect a proportionate amount of fine or colloidal material to stay in suspension at a definite time, providing other factors did not interfere or intervene?

This rather remarkable relationship can be used now as a factor in determining the colloidal content of soils, which can be accomplished in 15 minutes. All that is necessary is to disperse the soil in a certain volume of water, determine the density at the end of 15 minutes, and from this density, which represents material in suspension, calculate the percentage of the sample in suspension which is the percentage of colloids that that particular soil contains.

The 15-minute period has been chosen because the relationship seems to be the closest for nearly all soils at this length of time. It was selected from hydrometer readings taken every minute or every few minutes, extending from 1 minute to 24 hours. The fact that this same time element holds true for nearly all soils is most remarkable and goes to show that there is a fundamental basis for the phenomenon.

The material that stays in suspension at the end of 15 minutes is probably not all colloidal, but the colloids that might be carried down or settle are apparently compensated by the non-colloidal material staying in suspension. The amount of non-colloidal material staying in suspension at the end of the 15-minute period, however, is probably very small.

THE HYDROMETER AND PROCEDURE

The hydrometer employed for measuring the quantity of fine material staying in suspension was of a special type made for this purpose, which had a very large volume and considerable weight, both of which tended to make it very sensitive and accurate. This hydrometer was calibrated so that it would indicate directly on its stem grams of solid material staying in suspension in one liter of water.

An essential part of the hydrometer method for determining the colloidal content is a complete dispersion of the soil. Four different methods were tried for this purpose. These included (*a*) the standard rocking shaker, (*b*) the beater used in beating eggs, (*c*) pestling in a mortar by hand, and (*d*) the drink mixer shown in plate 1. These different methods were able to disperse the same soil in different lengths of time. The rocking shaker required 6 hours to effect an approximately complete dispersion; the egg beater, 1 hour; the hand pestling, 15 minutes; and the drink mixer 3 hours in the original form, but as finally modified only 9 minutes.

It was desired that the method adopted for dispersing the soil be not only efficient and rapid, but also that it do away with the personal element. At the outset the drink mixer seemed to fulfill all the essential requirements. The disappointment was very great, therefore, when it was discovered that in the form in which it is used for mixing drinks, more than three hours were required to effect a complete dispersion. Its failure to accomplish it in less time was due to the fact that the mixture in the cup was subjected to a circular motion without its being churned. Attention was directed, therefore, in correcting this defect, and happily it was most successfully corrected by putting a series of copper wires on the wall of the container to act as obstructions, and to prevent the circular motion.

The difference this slight change in the walls of the container made on the efficiency of the dispersing ability of the machine, is most remarkable, as seen by the fact that the time was reduced from more than 3 hours to only 9 minutes.

This machine in its final form, now, is a most effective machine for the dispersion of the soils.[2] The motor, without a load, goes at a speed of about 14,000 revolutions per minute and with a load, at about 9,000 revolutions per minute. The energy expended in dispersing the soil, therefore, can be easily imagined.

The method of pestling by hand in a mortar is very efficient, and very rapid,

[2] The idea of using this machine in the original form, was suggested in a conversation by Prof. H. Ries of Cornell University. As already stated, however, in the original form this machine is not practical for this work.

This machine is manufactured by the Hamilton Beach Manufacturing Company of Racine, Wisconsin, who have undertaken to make the special cups to be used in dispersing the soil. The complete outfit costs about $20.00

but the results are not always uniform and the dispersions not always as complete as that yielded by the motor and consequently is not recommended. With hand the soils can be dispersed in from 10 to 20 minutes, but they must be pestled vigorously even though the particles seem to be ground. They must be pestled and washed until all the soil is dispersed. The washings must stand half a minute before being decanted into the cylinder.

The length of time required for soil dispersal, at which the results of the hydrometer method correspond the closest with the results of the heat of wetting method, is 9 minutes for all the soils except for those whose organic matter content is either not well decomposed, or is difficult to disperse. Many soils with high contents of organic matter, from Illinois, Iowa, Michigan, and Minnesota behaved like the mineral soils with no organic matter, but a few soils, such as the Minnesota Carrington silt loam would not be dispersed at 9 minutes, but required about 30 minutes. Out of 15 of such organic soils examined, only 2 failed to give very close agreement with the heat of wetting method when dispersed only for 9 minutes. In such soils the organic matter could readily be seen to be not well decomposed. Such soils, which are readily recognized, should be stirred 30 minutes; all the other soils with organic matter should be stirred only 9 minutes. Those that need to be stirred 30 minutes will be exceedingly few according to this investigation thus far conducted. On the other hand, the error that might arise if these exceptional soils are stirred only 9 minutes, may not amount to more than 10 to 15 per cent. In the case of mucks and peats the method is not very successful because it is almost impossible to disperse those organic materials.

The 9-minute period of dispersion seems to effect almost a complete dispersion. For instance, Ontonagon silt loam gives 62.37 per cent of colloids when stirred 9 minutes and 66.20 per cent when stirred for 3 hours. Stalwart sandy loam gives 28.46 per cent when stirred only 9 minutes and 31.72 per cent when stirred 3 hours. These differences are certainly small when the great difference in time of stirring between 10 minutes and 180 minutes is taken into consideration.

In order to facilitate the dispersion, keep the material dispersed, and prevent flocculation and thus settling according to its physical laws, to each soil sample was added 5 cc. *N* KOH during the dispersion process. Most of the soils do not need the addition of KOH, because they are easily dispersed and remain suspended according to the physical laws governing the size of their particles, but there are some soils which have a tendency to flocculate after they are dispersed, and tend to settle in mass when they begin to flocculate. The addition of the KOH prevents this tendency to flocculate and the soil particles settle in the regular manner. In order that the general procedure might be uniform, the KOH was added to all the soils. This addition increased very little, if any, the amount of material that stayed in suspension at the end of 15 minutes, except in those soils that have a tendency to flocculate. Apparently the KOH serves the purpose mainly of stabilizing the soil

particles or colloids which have a tendency to flocculate. Some soils require more KOH than others in order to be stabalized.

The general procedure in the actual determination consisted of weighing out an amount of soil equivalent to 50 gm. on the oven-dry basis, although for practical purposes the hygroscopic moisture can be estimated if air-dry soils are used and allowance is made in weighing out the samples, placing it in the cup and filling the latter with distilled water to within 1 inch of the top. The cup was then connected to the stirrer of the motor and was stirred for exactly 9 minutes. The mixture was poured and washed into a liter cylinder having a total capacity of 1250 cc., a diameter of $2\frac{1}{2}$ inches, and a height of 18 inches. The hydrometer was then placed in the mixture and the cylinder containing the hydrometer filled to the top with distilled water. The hydrometer was taken out and the suspension was vigorously shaken by hand with the palm of one hand acting as a stopper. The cylinder was then placed on the table and the time immediately noted by a stop watch. The hydrometer was then placed in the mixture and at the end of 15 minutes the reading of the liquid was taken. Just half a minute before the end of 15-minute period, the hydrometer was gently pushed down into the liquid, to avoid any error in the reading caused by lag or sticking of the hydrometer. The temperature of the mixture was also noted. The amount of material shown on the hydrometer was then divided by 50, which was the amount of sample taken, and the result was the percentage of colloids in that soil.

In taking the sample, care should be exercised that the heavy types of soil are not in big lumps, because the water requires longer time to penetrate and to disperse these lumps. Also, soils that have a heavy content of alkali salts, should be washed before using. The samples taken should also be a very good representative of the whole soil.

With the 50 gm. of soil 1050 cc. of water was used. In the calculation of the results, however, only 1000 cc. was employed; the other 50 cc. was considered to be used up in wetting or saturating the soil.

In order to test out the method, various quantities of soil such as 25, 50, 75 and 100 gm., were employed. In every case 1000 cc. was used and in addition 1 cc. for every gram of soil, to make allowance for the water required to wet or saturate the soil. This additional water was added because the hydrometer measures the amount of suspensions in the entire column of liquid irrespective of the density with depth. In other words the hydrometer readings give the average of the densities for the entire column of liquid, i.e. from the top to the point where the solid column of soil is being formed by settling. Hence, to make the liquid columns above the various soils comparable, allowance was made for the water required to saturate the soils.

The hydrometer can be best read, in some cases when the column of liquid is at the top of the cylinder. In order, therefore, to have 1050 cc. of water with 50 gm. of soil and at the same time to have the column of the liquid at the top of the cylinder with the hydrometer floating in the liquid, cylinders of the

required size have been made.[3] With the use of these special cylinders, the results are comparable, matters are simplified, and time is saved in not having to measure the water. One can use, however, any regular liter cylinder that has a total capacity of about 1250 cc. An ordinary 1000 cc. cylinder may also be used by making a mark of the proper volume.

Changes of temperature make a difference in the results. A change of 1°F. makes a difference of about 0.350 per cent of soil colloids. For absolute comparison, therefore, the results must be reduced to the same temperature basis. In the present investigation the temperature of 67°F. has been chosen as a basis which is also the temperature at which the hydrometer has been calibrated. For readings above 67°F., therefore, 0.35 per cent must be added for each degree, to the percentage of colloids indicated by the hydrometer; and for readings below 67°F., 0.35 per cent must be subtracted for every degree of temperature. An example will make this point clear. Suppose that a soil gave 60 per cent of colloids at the temperature 77°F. To this 60 per cent must be added 3.5 per cent which will make a total of 63.50 per cent for this soil at the temperature of 67°F. If on the other hand this soil gave 67 per cent of colloids at the temperature of 57°F., from this amount must be subtracted 3.5 per cent.

The hydrometer was constructed to have a range between 0 and 60 gm. of dry material per liter of water and, therefore, can measure the colloidal content of a soil which may be as low as 1 per cent, taking a 50 gm. sample or 0.5 per cent taking a 100-gm. sample. It is graduated in 1 degree. This wide range of readings on the stem of the hydrometer was not needed in the colloidal determination but was placed on the hydrometer so that the latter could be used also in studying the rate of settling of soil particles, from which a distribution curve could be worked out showing the sizes and amounts of the soil particles. As shown in another publication (3) the hydrometer method lends itself in a remarkable way to this type of study. The hydrometer can be made considerably more accurate and sensitive by reducing its scale.

Many factors, such as flocculation, which might influence the rate of settling of soil particles on long standing are not effectively operative in short periods. Even those soils which have a tendency to flocculate are prevented from doing so by the addition of small amounts of KOH.

With only 9 minutes required to disperse the soil and only 15 minutes needed to make a hydrometer reading, the colloidal content of soils can be determined very quickly. Considering that after the first soil is dispersed, the second soil can be dispersed while the hydrometer readings of the first soil are being made, the colloidal content of more than three soils can be determined in one hour with one hydrometer.

Probably there are very few, if any, methods in soil physics work which are standardized so well as this method for determining the colloidal content of

[3] The cylinders are handled by the Taylor Instrument Company, Rochester, N. Y., who are also handling the hydrometers, and cost about $1.50 apiece.

soils. The hydrometer, for instance, floats and is governed entirely by physical laws with no outside disturbing factor and no personal element entering into it. The soil is dispersed at a definite speed and at a definite time by a mechanical means.

The method may appear arbitrary, but it is quite absolute because it is based upon the heat of wetting method which is quite absolute as far as it goes. Parker and Pate (5) made a comparison of the heat of wetting method with the water adsorption and base exchange method and found it to agree very well with these two methods and especially with the base exchange method. The procedure is arbitrary, but the results are absolute. Furthermore, considering that colloids are fundamentally a question of size of particles, and that the hydrometer method measures, in a final analysis, the size of particles, it seems to be the logical method for such a determination.

By following the general procedure outlined above the results of any soil can be duplicated almost exactly any number of times, provided that the temperature is constant or correction is made for it and also provided that a representative sample of the soil is taken every time.

Referring once more to the dispersing machine, there are two things that must be strictly guarded against: first, the cup must have the baffles or wires in it; and second, the paddle or button on the stirring rod tends to wear out on sandy soils; when it becomes flat, it must be replaced because in the flat condition it loses its stirring efficiency. With these two precautions, it can be said that this machine is most wonderful for dispersing soils for any purpose.

EXPERIMENTAL DATA

In table 1 are presented the data showing the relationship between the percentage of colloids as obtained by the heat of wetting method, and the percentage of the material staying in suspension in a liter of water at the end of 15 minutes, based on the amount of soil sample taken. There were four different quantities of soil employed 25, 50, 75 and 100 gm. per liter of water plus the additional water required for saturating the soil, but in this table the results for only the last three quantities are shown. The soils employed or tested include almost all the different classes coming from different localities and horizons. Many of these soils contain also various quantities of organic matter. These soils would certainly seem to represent an excellent array of diverse and representative types of soils for testing out the method.

An examination of table 1 shows at once that the relationship between the percentage of the colloids as determined by the heat of wetting method and the percentage of the material staying in suspension in a liter of water at the end of 15 minutes is very close in the majority of the soils. In many of the soils it is almost exactly the same, in a few it is not so close. Out of the 39 soils shown in the table, 3 show the widest disagreement. These are Strongs B_1 sandy loam, Minnesota Carrington silt loam, and California Yolo loam.

TABLE 1

Relationship between the percentage of colloids as indicated by the heat of wetting method and the percentage of material staying in suspension at the end of 15 minutes in a liter of water based on the weight of sample taken. Soils dispersed 9 minutes and results reduced to 67°F.

SOILS	PROPORTION OF COLLOIDS BY HEAT OF WETTING	PROPORTION OF COLLOIDS BY HYDROMETER METHOD		
		50-gm. samples	75-gm. samples	100-gm. samples
	per cent	*per cent*	*per cent*	*per cent*
Hillsdale sandy loam A	15.73	18.35	18.86	17.50
Hillsdale sandy loam B_1	18.70	19.00	19.25	18.60
Hillsdale sandy loam B_2	20.42	18.32	17.00	17.61
Strongs sandy loam A_1	5.18	8.30	8.48	8.74
Strongs sandy loam B_1	23.12	14.23*	13.85*	14.10*
Chippewa fine sandy loam A_2	12.02	11.68	10.32	10.82
Fox loam A_2	20.21	23.32	22.01	23.80
Fox loam B_1	27.65	27.00	28.30	28.47
Fox loam B_2	20.58	18.08	19.12	18.22
Onaway loam A_1	11.66	11.69	12.18	13.07
Onaway loam B_1	21.03	20.65	20.08	19.65
Onaway loam C	28.44	29.52	27.83	28.70
Stalwart loam A_1	22.49	24.22	24.02	25.10
Stalwart loam A_2	25.61	28.46	27.30	28.15
Stalwart loam B_1	21.01	24.87	25.10	26.00
Napanee silt loam A_1	35.51	39.98	40.38	40.83
Napanee silt loam B_1	41.09	48.10	47.60	46.90
Napanee silt loam C	50.76	53.08	52.10	51.65
Ontonagon silt loam A_1	60.65	62.57	62.00	61.54
Ontonagon silt loam A_2	60.30	63.82	62.90	62.08
Ontonagon silt loam B_1	71.30	73.06	72.80	71.80
Pennsylvania silt loam	24.50	29.88	26.10	25.70
Ohio silt loam	31.20	36.42	36.12	37.10
Tennessee silt loam	31.41	34.62	33.74	34.51
Michigan silt loam	39.04	44.60	44.18	43.10
Illinois clay loam	34.52	37.20	36.80	36.30
California yolo loam	48.51	38.00*	38.62*	37.40*
California yolo clay loam	59.54	53.94	54.10	53.65
California yolo clay	58.34	56.80	56.03	55.94
Minnesota Marion silt loam	45.40	36.95	37.18	37.62
Minnesota Carrington silt loam	50.62	38.12*	37.85*	37.02*
Iowa Bremer clay	49.40	51.69	51.03	50.90
Calcareous clay C	93.20	86.20	87.19	86.65
Brookston clay loam A	33.40	32.72	33.80	32.92
Brookston clay loam A_2	36.10	38.90	39.10	38.60
Brookston clay loam B	38.62	39.00	38.40	38.10
Greenville clay loam B	52.06	48.85	47.72	48.08
Cecil loam clay loam B	58.03	60.70	60.10	59.55
Manor schist loam B	34.00	30.01	30.90	30.60

* Not dispersed in 9 minutes.

The Strongs sandy loam was reddish brown and seemed to contain organic matter mixed with iron, which was hard to disperse in 9 minutes. The Minnesota Carrington silt loam contained considerable organic matter probably not in a thoroughly decomposed state and would not disperse in 9 minutes, but did in about 30 minutes. Other soils containing as large as, or larger organic matter than, the Carrington silt loam, such as the Illinois clay loam, Iowa Bremer clay, Michigan Brookston clay loam, and others, were easily dispersed in 9 minutes and as will be seen, gave a very good relationship. The California Yolo loam does not give such a big disagreement, but it does not give so close agreement as the other two soils of its series, Yolo clay loam and Yolo clay. No possible explanation can be suggested for this disagreement unless this soil contained some colloidal material which was not completely dispersed in 9 minutes.

The disagreement in the three soils mentioned above, although not very great, probably serves the purpose of indicating that there may be exceptional and abnormal soils which may not follow the relationship very closely. Excepting these unusual cases, however, the relationship is remarkably close considering the diversity of the soils, and the difficulty of taking absolute representative samples of soils for both sets of experiments. The hydrometer method would seem to be justified, therefore, in being adopted to determine the colloidal content of soils in 15 minutes as compared to one week, which is required by our present methods. It might be added here also that the agreement in the results between the heat of wetting and hydrometer methods is a great deal closer than the agreement in the results between the dye, water vapor, and ammonia methods as obtained by Gile et al. (4).

It is of the greatest significance to note that whether 50, 75, or 100 gm. of soil was employed, the percentage of colloids is the same in the different quantities and agrees with the percentage of colloids as determined by the heat of wetting method. This fact is very important, for it goes to show that the principle of the hydrometer method is basic and sound, and that the relationship between the two methods is fundamental and not accidental.

A very interesting thing revealed by the foregoing results is the fact that even soils with considerable amounts of calcium carbonate give a very good relationship. Calcareous clay and most of the soils from the C horizon contain considerable amounts of calcium carbonate and yet they show close relationship.

Since the hydrometer when floating follows entirely fundamental physical laws and is not disturbed by outside factors, the amount of material it indicates in a liter of water at the end of 15 minutes or at any length of time for the different soils, must be of the same average size of particles in the different soils. In other words, when two soils show different amounts of material in suspension in a liter of water at the end of a given time, this suspended material must be of the same average size of particles in both soils. Here then, is another quick way of determining the amount of material of the same average

size of particles in the different soils. It must be remembered that everything being equal, the rate at which soil particles settle, is governed mainly by their size.

Since the hydrometer method gives absolutely comparable results for the different soils, and since these results show such a remarkably close relationship with those obtained by the heat of wetting method, it goes to prove that the heat of wetting method has been a correct method for determining the colloidal content of soils. The hydrometer method apparently tends to measure the same thing as the heat of wetting method.

Following the above facts and reasoning further, it would seem reasonable to expect that if there were no experimental error in the heat of wetting method and if the soils were all completely dispersed in the hydrometer method, the results of the two methods would be still closer than they are.

The hydrometer method lends itself to determining the colloidal content of a soil in any condition of moisture, that is, whether the soil is oven-dry, or moist. If there has been a belief, therefore, that drying the soils affects their colloidal content, it can be easily tested out by this method. Preliminary studies with this method indicate, however, that a dried soil gives practically the same colloidal content as before drying. This statement, however, may not apply to all the organic soils.

Although all the different quantities of soil in the same quantity of water that have been employed, showed the same percentage of material in suspension at the end of 15 minutes, 50 gm. is probably preferable, except in soils which have a very low colloidal content, where 100 gm. is preferable.

In view of the remarkably consistent closeness of the relationship in many diverse types of soils between the percentage of colloids as shown by the heat of wetting and the percentage of the material staying in suspension at the end of 15 minutes in a liter of water, and in view of the fundamental basis governing this relationship, it would seem only logical to employ this relationship as a factor for determining very rapidly the colloidal content of soils.

Finally, by referring once more to the foregoing experimental results, it will be seen readily that the colloidal content of soils is infinitely higher than formerly was thought. This is, however, a new concept that is being forced upon us by the newer methods of studying colloids. These new methods are the water adsorption (4), base exchange (5), heat of wetting (2), and the hydrometer method. All these methods seem to agree pretty well in indicating this high colloidal content of soils.

If this high colloidal content is correct, it means that our present textural classification of soils is wrong and has to be changed radically to conform to these new concepts. Investigations looking toward a textural reclassification of soils are being conducted at this laboratory.

SUMMARY

The hydrometer method is presented as a new and very rapid method of estimating the colloidal content of soils.

By means of this method the colloidal content of a soil can be determined in 15 minutes. The colloidal content of three soils can be determined in less than one hour.

This is accomplished by the aid of a factor which has been discovered to exist between the colloidal content of a soil as determined by the heat of wetting and the percentage of the material staying in suspension in a liter of water at the end of 15 minutes. In other words, the percentage of the material staying in a suspension at the end of 15 minutes, as indicated by the hydrometer method, is equal to the percentage of colloids as determined by the heat of wetting method. There seems to be a fundamental basis for this relationship, as it has been found to hold remarkably close in all classes and types of soils, with very few exceptions which are due to rather undecomposed organic matter, or organic matter very difficult to disperse.

The soils are dispersed by a stirrer driven by a very fast motor and are contained in a specially constructed cup. The length of dispersion is 9 minutes except in a few special cases. To each soil sample is added 5 cc. of *N* KOH to stabilize the soil particle or colloids, as some of the soils have a tendency to flocculate. The hydrometer when floating is governed entirely by absolute physical laws. That being the case, the results it gives for the different soils must be absolutely comparable. This means then that the amount of soil material staying in suspension at any given time in a liter of water must be of the same average size of particles for the different soils since, everything being equal, the rate at which soil particles settle, is governed by their size.

Since the hydrometer method gives absolutely comparable results for the different soils and since these results show a very close relationship with the results of the heat of wetting method it means then that the heat of wetting method has been a correct method for determining the colloidal content of soils. Evidently both methods tend to measure the same thing

By following the directions closely for executing the determination, the results of any soil can be duplicated almost exactly any number of times.

A new and special hydrometer has been constructed for measuring the density of the soil suspensions, which is very accurate and sensitive and gives grams of dry material per liter of water directly.

It is believed that this hydrometer method can be employed now with confidence and assurance for determining the colloidal content of soils and such determination seems to be accurate, except in a very few special cases.

Since the colloidal content of soils, as indicated by the hydrometer method, as well as by the heat of wetting, water adsorption, and base exchange methods is infinitely higher than used to be believed, a new and radical textural reclassification of soils is needed.

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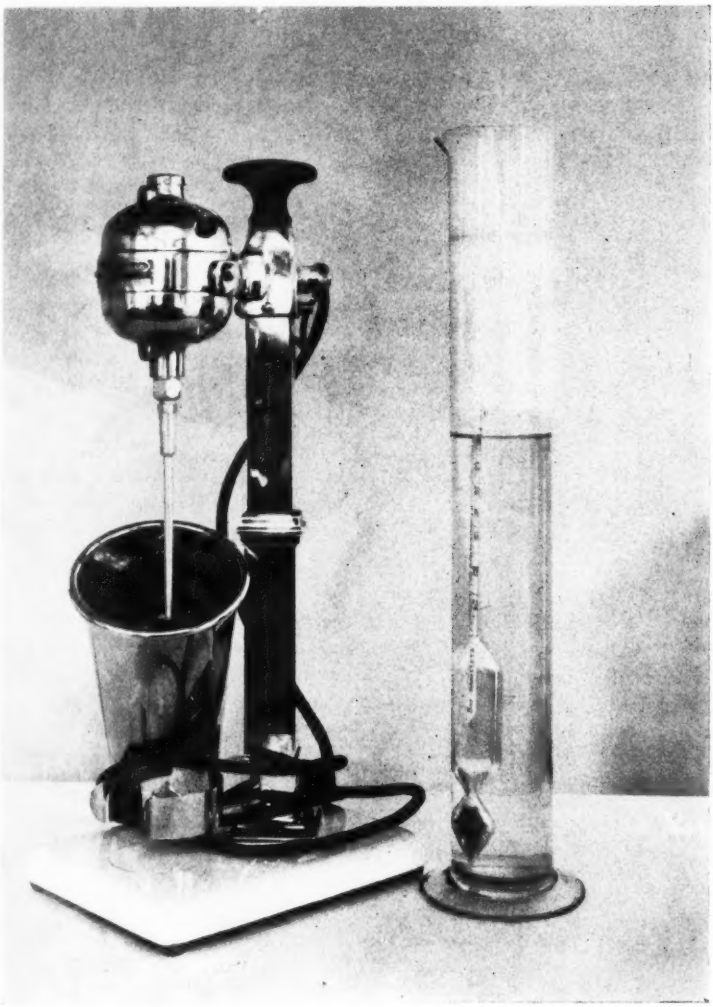
PLATE 1

SHOWING THE DISPERSING MACHINE, CYLINDER AND HYDROMETER, IN THE DETERMINATION OF SOIL COLLOIDS



UNIV. OF MICH.

BOOK REVIEW[1]

Données Numériques de Cristallographie et de Minéralogie. By M. L. SPENCER. *Section D of Tables Annuelles de Constantes et Données Numériques de Chimie, de Physique et de Technologie.* Edited by Ch. Marie. Vol. V—Years 1917 to 1922, inclusive: Part 1, pp. i-xl, 1–804 (1925); Part 2, pp. i-lii, 805–1934 (1926). Gauthier-Villars & Cie, Paris; The Cambridge University Press, Cambridge; University of Chicago Press, Chicago, 1925. Price, cloth, $25.00, paper $22.00.

Section D, Crystallography and Mineralogy (pages 1285–1403) comprises six subdivisions (in French), as follows: I. Crystallography of Minerals, II. New Crystalline Form of Minerals, III. Crystallography of Inorganic Compounds, IV. Crystallography of Organic Compounds, V. Structure of Crystals from X-ray Data, and VI. Miscellaneous Data. (Elements in earth's crust, specific heats of various minerals, hardness of minerals and rocks, and so forth.)

Volume V of the Annual Tables, of which Section D is a part, contains data accumulated during the years 1917 to 1922 inclusive. The publication of a volume each year was interrupted by the World War and the inclusion of six year's data in one volume has been necessitated by the afterwar conditions in many countries.

These Tables are not intended to take the place of, or compete with, the International Critical Tables. They are planned to make available an annual non-critical summary of the material obtained during a current year, it being the function of the Critical Tables to present the data after a critical examination.

The present volume is in seven sections. It may be purchased in sections or as the complete volume.

[1]This review was prepared by Prof. Walter C. Russell, of the New Jersey Agricultural Experiment Station.